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A Study of the Normal Anatomy of the Masticatory Apparatus of Macaca Mulatta

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**A STUDY OF THE NORMAL ANATOMY OF THE MASTICATORY
APPARATUS OF MACACA MULATTA**

by

Dennis E. Zielinski

**A Thesis Submitted to the Faculty of the Graduate School
of Loyola University in Partial Fulfillment of
the Requirements for the Degree of
Master of Science**

**June
1965**

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LIFE

Dennis Edward Zielinski, was born in Chicago, Illinois, on January 13, 1939.

He graduated from DePaul Academy High School, Chicago, Illinois, June, 1957. From September, 1957 to June, 1959, he attended the College of Liberal Arts and Sciences of Loyola University in the pre dental curriculum. In September, 1959, he entered Loyola University Dental School and was graduated in June, 1963 with a Doctor of Dental Surgery degree.

In July of 1963, he enrolled in the Graduate School of Loyola University to pursue a Master of Science degree in the Department of Oral Biology and was graduated June, 1965.

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Finally, special gratitude is due to my mother whose patience and understanding knew no bounds and whose help in typing the copies of the thesis is greatly appreciated.

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CHAPTER 1

INTRODUCTION

This investigation was undertaken to study the normal anatomy of the masticatory apparatus; namely, the teeth, skeleton, temporomandibular joint and muscles of mastication of the *Macaca mulatta* monkey. Hartman, in 1933, was the first to give a comprehensive description of the gross anatomy of this primate. However, he did not present a detailed description of the masticatory apparatus.

Macaca mulatta has been widely used, in all aspects of dental research, to study the experimentally induced abnormal, and the resultant influence such dental research has on man. The normal masticatory apparatus of the Macaque has received little attention. It was therefore felt that a study of this area should be undertaken.

It is hoped that this investigation will:

1. Form a basis for designing future experiments on the masticatory apparatus of this primate.
2. Help determine the validity of application of data obtained experimentally.
3. Be used as a basis for studying any variation from normal following experimentation in this area.

CHAPTER 11

REVIEW OF THE LITERATURE

The normal human masticatory apparatus has been the object of many investigations. Sarnat (1951), and Sicher (1952), (1962), did extensive studies of the anatomy and function of the temporomandibular joint, and of condylar growth. Symons (1952) showed that the secondary condylar cartilage appears superior to the developing mandible at the 50 mm. stage of the embryo. Weinmann and Sicher (1955) described the effect of condylar growth on the condylar angle. Choukas (1958) discussed the attachment of the disc to the condyle and showed that muscle fibers of the medial superior part of the upper head of the lateral pterygoid were attached to the fused capsule and disc.

Lindblom (1960), and Frommer and Parker (1963), studied the morphology of the glenoid fossa and the relationship of condyle to fossa using cephalometric radiographs. Thilander (1964) described the orientation of the collagen fibers in the disc and its innervation.

According to Baume and Becks (1950), "Macaca mulatta is a species of monkey which ranks among the series of Catarrhine or Old World monkeys. The Macaque is of the Primate

order, the suborder Anthropoides, and range next to the family Hylobatidae (Gibbons) followed by the family of Pongidae (great apes)."

The literature is meager in the area of descriptive anatomy of the masticatory apparatus of *Macaca mulatta*. Sullivan (1933) first described the temporomandibular joint and associated muscles of this primate. He stated:

"The temporomandibular joint is a diarthroidal joint between the mandibular condyle, and the mandibular fossa and articular tubercle of the temporal bone. The zygomatic process of the temporal bone on its inferior surface has an articular tubercle; behind and dorsal to this lies the mandibular fossa. Posterior to the fossa and projecting inferiorly is a strong spine, the post articular process."

He also observed the rhesus mandible to be capable of depression, elevation, protraction, retraction, and lateral movement. Ayer (1948) described the morphology of the glenoid fossa of *Simnopithecus entellus* (Indian langur). Sarnat and Engel (1951) dealt with the effect of condylectomy on mandibular and facial growth. They divided the cartilage growth center into three zones: 1.) Chondrogenic, 2.) Cartilaginous, and 3.) Osseous. They gave a detailed description of the osseous anatomy of the ramus, condyle and glenoid fossa. Baume (1951) studied the endochondral and appositional growth of the Macaque mandible, and the sutural growth of the maxilla. He noted that osseous resorption and apposition at

the sites of muscle insertions of the mandible were performed by tendinous perimysia in place of distinct periosteum. DuBrul and Sicher (1954) did a comparative anatomic study of the mandibles of different primates, starting with Tupaiidae (tree shrew) and progressing to *Homo sapiens*. Hill (1959) investigated the normal anatomy of the temporomandibular joint of *Callimico Goeldii* (a marmoset), and found it to be similar to that of *Macaca mulatta*. James (1960) described the differences in morphology of the teeth, maxilla, zygomatic arches, cranium, and mandible of the different families of primates. He agreed with Sarnat and Engel (1951), Ayer (1948), Hill (1959), Schwartz and Heulke (1963), and Robinson (1963) in finding fibers of the lateral pterygoid inserting into the meniscus. Heurlin (1960) observed the skeletal changes which occurred following fracture dislocation of the mandibular condyles of adult Rhesus monkeys. He found in the case of a unilateral fracture that the teeth on the affected side were in premature contact; in bilateral fracture dislocations an anterior open bite occurred. Baume and Derichewieter (1961) investigated the effect that continuous anterior displacement of the mandible in young *Macaca mulatta* monkeys has on the condylar growth center. They observed, in the condyle, an increased cellular proliferation in a dorsal and posterior direction with little change occurring in the

temporal portion of the craniomandibular articulation. An orthodontic appliance was used to maintain the mandible in a protruded position. Robinson (1961), (1963) found the articular disc of the Macaque to be attached to the condyle at its periphery thus disagreeing with Sarnat (1951) who stated that the disc is attached to the condyle via the capsule. Hersberg and Sarnat (1962) described the changes in trabecular orientation in the mandibular ramus following unilateral and bilateral condylectomy. These changes were consistent with the altered mandibular functions and changes in stress produced on the ramus by the associated muscles. Kendrick (1962) observed that ephiphyseal plate proliferation of autogenous metatarsal transplants did not make any significant contribution to mandibular growth but that the articular cartilage of the graft appeared to be the growth contributing factor. Aitchison (1963) is in agreement with James (1960), and Baume and Becks (1950) on the fact that the chimpanzee cannot perform lateral excursions of the mandible due to the large interlocking canines. This view is not supported by Sullivan (1933) concerning *Macaca mulatta*. Schwartz and Huelke (1963) did an excellent study of the normal anatomy of the masticatory muscles of *Macaca mulatta*. They observed that part of the deep head of the masseter muscle originates from the temporomandibular ligament and that the anterior

bellies of both digastric muscles were united at the midline.

Comparative anatomic studies of the dentition of the primates, including *Macaca mulatta* are numerous. Cousin (1941) gave the following dental formula for the Macaque:

Deciduous	DI	$\frac{2}{2}$	DC	$\frac{1}{1}$	DM	$\frac{2}{2}$
Permanent	I	$\frac{2}{2}$	C	$\frac{1}{1}$	P	$\frac{2}{2}$ M $\frac{3}{3}$

He found that the progressive evolutionary changes of the dental arch, from one in which the right and left premolars and molars are aligned parallel to each other to one in which they are arranged in a parabolic arch, is associated with the increased width of the intercondylar distance, with the reduction of the canines, and with the more vertical position of the incisors. Baume and Becks (1950) divide the development of the dentition of the Macaque into four periods:

- Period I. The time interval between the appearance of the lower first permanent molars and establishment of occlusion with the upper permanent molars.
- Period II. When the permanent first molars are in function with all the deciduous teeth present.
- Period III. Interval during which the deciduous incisors are replaced by the permanent ones.
- Period IV. Initiated by the eruption of the permanent second molars followed by a rapid and simultaneous replacement of the deciduous molars

by the premolars. This period is terminated after the eruption of the permanent canines.

Ray (1953) presented a brief outline of the evolutionary development of the dentition, from fish to man. Sahecke (1961) divided the molars of this primate into three types:

- Type 1. Paracone is connected to Hypocone
- Type II. Four cusps connected at central pit
- Type III. Protocone is connected with Metacone

The third molars were the largest teeth, in mediobuccal dimension, in the lower jaw. Swindler (1961) reported the first permanent tooth to calcify was the mandibular first molar at 153 to 169 days in gestation - (average gestation period, 170 days). Mills (1961) discerned two distinct phases in the chewing pattern of primates:

On the side toward which the mandible moves:

- Phase 1. The lower buccal cusps slide in the grooves between the upper buccal cusps and similarly the lower lingual cusps slide between the upper lingual ones.

On the side from which the mandible moves:

- Phase II. The lower buccal cusps slide down the buccal face of the upper lingual cusps.

These two phases of occlusion occur simultaneously on opposite sides of the mouth producing a balanced occlusion. Mills did not mention the occurrence of the "Bennet shift" during lateral

excursions.

The masticatory apparatus of other animals has been studied by a few investigators. Sisson (1914) described the anatomy of the craniomandibular articulation of the horse. Brazier (1926) studied the morphology of the mandible, and temporal and masseter muscles of the wood rat. Kvam (1951) discussed how the osseous morphology of the temporomandibular joint of the herbivores, carnivores, and omnivores influences the type and extent of mandibular excursions. Cunat, Bhaskar, and Weinman (1956) observed the embryological development of the condyle and squamous bone of the rat. Pollock (1962) compared the masticatory apparatus of a rodent to that of a lagomorph.

CHAPTER III

MATERIALS AND METHODS

Three *Macaca mulatta* monkeys of mixed sex were obtained from Shamrock farms of the state of New York. Their age, determined by crown-rump length, dental development, weight and hand length, was twelve, fifteen and seventy-two months.

A gross dissection of the muscles of mastication and temporomandibular joint was done on two animals; twelve and seventy-two months old respectively. The animals were sacrificed, decapitated at the clavicular line, and the heads placed in a ten percent formalin solution for five days after which they were transferred to a twenty percent alcohol solution. Dissection of the masseter, lateral and medial pterygoid, temporal, digastric, geniohyoid, and mylohyoid muscles was carried out, noting points of attachment, muscle form, and muscle fiber direction. The anatomy of the articular surface of the temporal bone, condyle, temporomandibular capsule, and insertion of the lateral pterygoid was studied. Two condyles and associated articular discs were removed. The discs morphology and mode of attachment to the condyle were examined.

Two heads were hemisected with a Stryker autopsy saw. Lateral and posterior-anterior cephalometric radiographs were taken using Kodak medical X-ray film, with a double inten-

sifying screen, exposed for one second at 115 KVP and 15 MA. The target film distance was thirty-nine inches. All radiographs were taken with the dentition in centric occlusion and were used to determine the normal condyle-fossa relationship in this occlusal position.

Two dry skulls, one adult and one immature were used to study the osteology of the head. Areas of muscle origin and insertion, dentition, and craniomandibular joint morphology were studied. All dry and wet specimens were photographed using a Kodak Startech camera, M2B flash bulbs, and Ektachrome 127 film.

The third animal, which was fifteen months old, was restrained with a "squeeze cage" and anesthetized with 64 mg. per five pounds of body weight of pentobarbital sodium U.S.P. (Nembutal). The chest was opened, the right atrium incised and a glass canula placed in the left ventricle and into the ascending aorta. The descending aorta was clamped off and the head and neck of the animal perfused with sodium citrate 7% followed by 10% buffered formalin. After fixation the animal was decapitated at the clavicular line and the head placed in a 10% formalin solution for five days. The skin, subcutaneous tissue and muscles were dissected away from the specimen. The calvarium was removed with a Stryker autopsy saw and the contents of the cranium extracted. A cut was then

made along the superior aspect of the petrous portion of the temporal bone, starting just posterior to the external auditory meatus and extending medially to the posterior clinoid process. A second cut was made along the superior edge of the greater wing of the sphenoid bone and extended to meet the first. A third cut passed through the mandibular neck, horizontally. The wedge shaped "in block" section was then dissected free and placed in a 10% solution of formalin. The same procedure was followed on the opposite condyle. Both specimens were decalcified in a solution consisting of equal parts of a sodium citrate solution and a formic acid solution for seven days and then embedded in paraffin. One temporomandibular joint was sectioned coronally, the other sagittally. The sections measured 8-10 microns in thickness, were stained with hematoxylin and eosin, and mounted in Canadian balsam. These slides were used to study the endochondral growth center of the young Macaque.

Masticatory movements were observed of animals during feeding. In addition, slow motion pictures were taken of animals eating to determine the normal pattern of mandibular movements.

CHAPTER 1V

FINDINGS

1. SKULL

MAXILLA (Figs. 4,5,6,7) The maxilla consisted of a body proper, which contained the maxillary sinus, and the frontal, zygomatic, palatine, and alveolar processes.

The frontal process arose from the anteromedial aspect of the body and sloped posterosuperiorly, terminating at the frontomaxillary suture. It was bounded medially, by the nasal bone, and laterally by the lacrimal bone which formed part of the medial wall of the orbit and contained the lacrimal canal. The two frontal processes of the opposite maxillae met in the midline, superior to the nasal bones.

The palatine process arose from the medial aspect of the maxillary body and was composed of a horizontal plate of bone situated at right angles to the alveolar process. This process separated the oral cavity, inferiorly, from the nasal cavity, superiorly. Anteriorly, the opposing palatine shelves met in the midline as a linear ridge of bone which divided the incisive foramen in half. Behind the incisive foramen they came in contact at the median palatine suture and terminated, posteriorly, at the transverse palatine suture adjacent to the palatine process of the palatine bone. The superior surface of

the palatine process was convex and the inferior surface concave, mediolaterally; the greatest point of concavity being reached in the middle one-third of the process. In the region of the median palatine suture the bone was slightly elevated and formed an anteroposterior prominence.

The alveolar process projected inferiorly from the body of the maxilla and contained the central and lateral incisors, canine, premolars and molars. Anteriorly, the alveolar process was inferior to the pyriform aperture and laterally, in the region of the maxillary second molar, became continuous with the zygomatic process of the maxilla. The dentition, anteriorly, formed a smooth arc and posteriorly was arranged in two opposing parallel rows. The buccal cortical plate of the alveolar process was thinner and projected further inferiorly than the lingual cortical plate. Posteriorly the maxillary tuberosity was narrow, mediolaterally, and was in contact with the pterygoid process of the sphenoid bone and the pyramidal process of the palatine bone. The pterygopalatine fosse was narrow, anteroposteriorly, and superiorly led into a very short inferior orbital fissure which became confluent with the superior orbital fissure in the posterior part of the orbit.

The zygomatic process of the maxilla projected, lateroposteriorly, from the body of the maxilla, in the region of the second permanent molar and met the zygomatic bone at the

oblique zygomaticomaxillary suture. This suture traversed from the inferior orbital rim, just lateral to the infraorbital foramen, lateroinferiorly, to the inferior border of the zygomatic bone where it served as the anterior boundary for the superficial head of the masseter muscle.

The superior portion of the body of the maxilla above the maxillary sinus, formed a segment of the orbital floor which was bounded medially by the lacrimal and ethmoid bones, laterally by the zygomatic bone, and posteriorly terminated at the inferior orbital fissure. This orbital segment was traversed by the infraorbital groove which contained the infraorbital nerves and vessels. This groove was not covered by any bone for its entire anteroposterior length in the orbit. It became a canal upon penetration of the infraorbital rim and ended in two to three distinct infraorbital foramina, about four millimeters below the superior edge of the infraorbital ridge, on the anterior aspect of the body of the maxilla.

PALATINE BONE (Figs. 5,14) The palatine bone consisted of two bony plates, a horizontal and a vertical process, which were orientated at right angles to each other. The horizontal plate was joined, laterally, by the alveolar process, anteriorly by the posterior portion of the palatine process of the maxilla, and medially by the opposite horizontal palatine process. In the midline of the posterior free edge of

the horizontal process projecting backward, was the posterior nasal spine which, superiorly, became continuous with the vomer bone of the nasal cavity. The pyramidal process of the palatine bone arose from the posterolateral corner of the horizontal process. This projection extended posterolaterally and ended between the anteroinferior corners of the medial and lateral pterygoid plates. Immediately posterior to the transverse palatine suture and medial to the maxillary tuberosity was the greater palatine foramen.

The vertical process of the palatine bone projected postero-superiorly and formed the lateral, posterior wall of the nasopharyngeal duct. This process was in contact with the anterior surface of the medial pterygoid plate. Superiorly, the vertical process terminated in an orbital process, which contributed to the posterolateral wall of the orbit.

PTERYGOID PLATES (Figs. 5,10,14,21,22) The medial and lateral pterygoid plates projected inferiorly from the cranial base, just posterior to the maxillary tuberosity.

The medial pterygoid plate was much smaller than the lateral pterygoid plate and posteriorly formed the medial wall of the nasopharynx. The pterygoid hamulus extended posteroinferiorly from the lower border of the medial plate.

The lateral pterygoid plate flared out both in an anteroposterior and superoinferior direction. The inferior

border of this plate was continuous with the posterior portion of the pyramidal process. Directly behind the posterior edge of the lateral pterygoid plate were the oval and spinous foramina. Superiorly, at the root of this plate and on its lateral surface were two small foramina. The pterygoid plates of the sphenoid bone were anterior and medial to the squamosal surface of the temporomandibular articulation. No lacerated foramen was found in the cranial base.

ZYGOMATIC ARCH AND BONE (Figs. 4,5,6,7,10,14) The zygomatic bone was composed of the body proper, and the fronto-sphenoid, maxillary and temporal processes. The frontosphenoid process projected superiorly from the body and connected with the frontal bone superiorly, and the sphenoid bone posteriorly. The maxillary process of the zygomatic bone extended anteroinferiorly and united with the maxilla at the zygomaticomaxillary suture. The temporal process progressed posteriorly and connected with the zygomatic process of the temporal bone at the zygomaticotemporal, suture and formed the anterior one-third of the zygomatic arch. The remaining posterior two-thirds of the arch were formed by the zygomatic process of the temporal bone. The arch was triangular in cross section, being wide inferiorly and narrow superiorly, and reached its maximum inferosuperior width at the point of greatest convexity of the anterior articular eminence. The zygomatic arch served as

the origin for both the superficial and deep heads of the masseter muscle and for the superior attachment of the temporomandibular ligament. With the dentition in centric occlusion, the coronoid process was centrally located between the lateral cranial surface and the medial surface of the arch. At the root of the zygomatic arch just anterior to the external auditory meatus, was the posterior articular process.

MANDIBLE (Figs. 4,6,7,8,9,10,14,19) The mandible was a U-shaped bone, consisting of two bilaterally symmetrical halves fused at the symphysis. Each half was comprised of a thick body which contained the alveolar process and teeth, and a thin ascending ramus which terminated superiorly in the condyloid and coronoid processes. These processes were situated lateral to the inferior border of the mandible. Lingual to the central and lateral incisors was a shelf of bone (Simian shelf), which sloped from the incisors posteroinferiorly. Immediately below this shelf were two to three foramina. The mandibular incisors and canines were anterior to the inferior border of the mandible. The internal oblique ridge was prominent and extended from the ridge of the mandibular neck, inferiorly, to lingual of the third molar. The retromolar triangle was distal to the mandibular third molar and was situated between the external and internal oblique ridges. The mylohyoid line extended from the lingual aspect of the distal cusp of the

third molar, anteroinferiorly, to the symphysis.

The body of the mandible had its greatest height anteriorly, in the region of the incisors, and its least height posteriorly, at its junction with the ramus. There was no mental protuberance, but instead there was a posteroinferior sloping of the mandibular body at the symphysis. The mental foramen was situated in the lower one-third of the mandibular body, between the first and second premolars.

RAMUS (Figs. 8,19) Posteriorly, the body of the mandible united with the thin ramus distal to the mandibular third molar. Ascending, superiorly, the rami diverged, laterally. The anterior border of the ascending ramus was comprised of the anterior surface of the coronoid process, superiorly, and inferiorly of the external oblique ridge, which terminated on the body, buccal to the mandibular third molar. On the lateral surface of the ramus, inferior to the sigmoid notch and coronoid process, was a shallow fossa (Fig. 19) which extended, inferiorly, to the occlusal level of the teeth. This fossa was ovoid in shape and was the region of insertion for the fibers of the deep head of the masseter muscle. The sigmoid notch was shallow and separated the shorter condyloid process from the higher coronoid process, which curved posterosuperiorly. The posterior surface of the ramus extended from the posterior aspect of the condyle, superiorly, to the gonial

angle, inferiorly. The gonial angle was round and convex and presented no evidence of an angular process. It ended on the inferior border of the mandibular body at a shallow antegonial depression. The bone of the gonial angle was very thin and curved medially, forming a concavity on the inner surface of the ramus. This medial curling of the angle was the result of muscle tension of the medial pterygoid.

On the medial aspect of the ramus were two bony ridges; the ridge of the mandibular neck and the temporal crest. The ridge of the mandibular neck began below the condyle and traversed anteroinferiorly. The temporal crest originated inferior to the coronoid process, progressed inferiorly, and united with the ridge of the mandibular neck, half way down the medial surface of the ramus. At the junction of these two ridges was a fossa which served as the area of insertion for part of the deep head of the temporal muscle. The ridge of the mandibular neck continued anteroinferiorly and became the internal oblique ridge which terminated lingual to the third molar. The mandibular foramen was located in the middle of the ramus, anteroposteriorly and was inferior to the ridge of the mandibular neck. Immediately posterior to the foramen the groove of the mandibular neck continued posterosuperiorly. This groove carried the neurovascular bundle to the lower dentition before it entered the mandibular canal.

2. DENTITION

(Figs. 5,6,8,9,11,12,31) The adult dental formula for *Macaca mulatta*, as stated by Cousin, (1941) is I C P M . The average eruption dates of these teeth according to Schultz in Hartman and Straus (1933) is:

Permanent Dentition Eruption Dates (Months)

	Mandibular Teeth	Maxillary Teeth
Central Incisors	33	31
Lateral Incisors	36	38
Canines	46	48
First premolar	47	49
Second premolar	49	48
First molar	20	21
Second molar	42	42
Third molar	79	90

The maxillary and mandibular incisors were inclined labially. The upper incisors were inclined at a greater angle than the lower incisors. The incisal edges of the mandibular incisors occluded with the cingulum of the maxillary incisors. The maxillary central incisors were much wider in mesiodistal width than the maxillary lateral incisors. The incisal edges of all four teeth were at the same level. There was a diastema between the distal surface of the maxillary lateral incisor and the mesial surface of the maxillary canine which facilitated the massive, pointed cusp of the mandibular canine. The maxillary canine was the largest tooth in the mouth. The crown of this tooth was well developed and impeded extensive lateral excursions due to its

interlocking action with the mandibular teeth. The canine root curved superoposteriorly and terminated midway between the infraorbital rim and the occlusal level of the maxillary teeth. The maxillary first and second premolars were similar to each other in morphology. The fossa and transverse grooves of their occlusal surfaces were shallow and their bucco lingual diameter was greater than their mesiodistal diameter. The mesial half of the occlusal surface of the first premolar was found to be concave mesiodistally to facilitate the cusp of the posteriorly inclined mandibular first premolar. Both the maxillary first and second premolars were found to have two thin buccal roots and one lingual root. There were three permanent maxillary molars. The first molar was the smallest in both buccolingual and mesiodistal width; the third molar the largest. The mesio-buccal cusp of the maxillary first molar occluded into the buccal groove of the mandibular first molar. The cusps, transverse enamel ridges, grooves and fossae were most prominent in the maxillary third molars. The contact points of all the upper cheek teeth were in the occlusal one third. The maxillary molars all had two buccal roots and a single large lingual root, which was longer than either of the buccal roots.

The six anterior mandibular teeth were similar in morphology to the maxillary anterior teeth. The centrals

did not have as great a mesiodistal width as did the maxillary centrals and the mandibular canine was not as well developed as its upper counterpart. The mandibular canine occluded into a diastema between the maxillary lateral incisor and canine. The mandibular first premolar was especially adapted to occlude with the large maxillary canine. The labial surface of the crown of this tooth was inclined posteriorly, at a 45° angle, and there was a facet worn on the mesial surface. The first mandibular premolar had a large mesial root and a thin, short distal root. The mesial and distal roots of the second mandibular premolar were of equal diameter and length. The mandibular first molar was the smallest of the lower teeth, the third molar was the largest. The mandibular third molar had a fifth cusp at the distal surface of the crown. This cusp occluded with no antagonist in the maxillary arch. Each of the three molars had a mesial and distal root of equal diameter and length.

The long axis of the cheek teeth of the maxillary arch was lingually inclined, that of the mandibular cheek teeth buccally inclined. The dental arches, both maxillary and mandibular were constricted, lingually, in the region of the third molars, which resulted in there being less space between the lingual surfaces of the right and left third molars than between the lingual surfaces of the right and left first premolars. The

anteroposterior length of the dental arches was roughly twice the transverse width.

Macaca mulatta received a deciduous and a permanent set of teeth. Upon loss of a permanent tooth, there was no replacement.

3. TEMPOROMANDIBULAR JOINT

The temporomandibular joint of *Macaca mulatta* is a complex diarthroidal articulation between the cranial base and the mandible. It is classified as complex on the basis of the articular disc dividing the joint space into an upper compartment, in which gliding movements occur, and a lower compartment in which hinge or strictly rotary movements transpire.

CONDYLE (Figs. 6,8,9,14,15,30,31,32) The condyle of this primate was an ovoid body measuring 12 to 14 mm. transversely and 6 to 8 mm. anteroposteriorly. It was situated atop a short mandibular neck and orientated at right angles to the vertical ramus. The coronoid process at the anterior end of the sigmoid notch, extended 2 to 4 mm. above the level of the condyle. The articulating surface of the condyle was convex anteroposteriorly and slightly concave mediolaterally. It was divided into two areas, an anterior surface facing directly upward, and a posterior surface facing backward. It was the anterior surface that articulated with the posterior slope of the articular eminence. The posterior surface was inferior to the fossa and

sloped downward and backward. This surface could be divided into a lateral, middle, and medial one-third. The middle one-third was concave to allow room for the posterior articular process. The outer and inner one-third were slightly convex. The lateral pole of the condyle did not project beyond the zygomatic arch. The medial pole of the condyle projected considerably, beyond the medial surface of the ramus. Immediately below the inner pole, the ridge of the mandibular neck proceeded inferiorly, united with the temporal crest and then progressed inferiorly as the internal oblique ridge. The posterior facet gradually blended with the posterior surface of the mandibular neck.

According to Sicher (1952) if lines were projected through the horizontal axes of both human condyles, they would cross at the anterior edge of the foramen magnum. If this procedure was followed in Macaca, the lines would meet at a point posterior to the anterior edge of the foramen magnum.

CRANIAL ARTICULAR SURFACE (Figs. 5,13,14,15,30,31)

The cranial articulating surface of the temporomandibular joint was situated anterior to the external auditory meatus, on the temporal squama. This surface included a slightly convex anterior articular eminence, a shallow narrow articular fossa, and a well developed posterior articular process. The mediolateral width of the cranial articular surface was approximately twice

that of the anteroposterior length. There was no distinct bony ridge demarcating the lateral border of the fossa or eminence. Laterally, both fossa and eminence gradually fused with the inferior border of the posterior root of the zygomatic process of the temporal bone. The posterior boundary of the cranial articulation was marked by a crevice, the squamotympanic fissure. This fissure separated the posterior articular process from the tympanic bone. It continued anteriorly and medially and became divided into two fissures by the edge of the roof of the tympanic cavity - tegmen tympani - projecting downward. The resulting two fissures were the anterior petrosquamosal, and the posterior petrotympanic.

Medial to the posterior edge of the lateral pterygoid plate the petrosquamosal fissure became confluent with the oval foramen. The lateral pterygoid plate marked the medial extension of the temporal articular surface.

POSTERIOR ARTICULAR PROCESS (Figs. 5,13,14,15,30, 31) At the posterior border of the articular fossa was a bony prominence, the posterior articular process. It was well developed and situated immediately anterior to the external auditory meatus. The eminence was wider at its base than at the apex and was obliquely orientated, mediolaterally, parallel to the condyle. At its greatest height the process extended below the tympanic bone. Progressing medially it gradually decreased in

height and became continuous with the squamous temporal at the point where the tegmen tympani began to project into the squamotympanic fissure.

ARTICULAR EMINENCE (Figs. 15,30,31) The articular eminence was situated at the base of the zygomatic process of the temporal bone and marked the anterior boundary of the articular fossa. It was convex anteroposteriorly, and slightly concave mediolaterally. The posterior slope of the anterior articular eminence articulated with the mandibular condyle via the articular disc. No articulation occurred in the fossa. The articular eminence had no distinguishable anterior slope since the inferior border of the zygomatic process was continuous with the crest of the eminence.

FIBROUS CAPSULE (Figs. 16,17) The fibrous capsule of the temporomandibular joint attached superiorly to the medial, anterior and lateral portions of the temporal bone bounding the articular fossa and eminence. Posteriorly, the capsule was attached to the entire anterior surface of the posterior articular process. Laterally, the capsule thickened considerably to form the temporomandibular ligament. The ligament originated from a wide area on the lateral border of the articular eminence and fossa and inserted on the mandibular neck, below the condyle. The anterior fibers of the ligament were oblique, the posterior ones vertical in direction. Poster-

ior fibers of the deep head of the masseter originated from the anterior aspect of the ligament. The ligaments, acting bilaterally, limited the movements of the joint and protected the retrodiscal tissues from excessive compression (Sicher 1952).

The capsule inserted, anteriorly, to a sharp bony ridge below the anterior articular surface of the condyle, and posteriorly attached low on the mandibular neck. The medial and lateral attachments were just below the articular disc.

DISC (Fig. 15) The disc of the temporomandibular joint was a fibrous oval of firm consistency located between the temporal squama and the mandibular condyle. It was bound down to the medial and lateral poles of the condyle. There was no fusion of disc with capsule at these poles. The disc fused with the capsule anteriorly. Posteriorly the disc was attached to the capsule by a band of loose connective tissue - retrodiscal pad, which became extended when the disc and condyle were protracted.

The superior surface of the meniscus was concave anteroposteriorly and horizontal mediolaterally; the inferior surface was concave in both directions. It was thinnest in its center and thickest in the posterior region; anterior to the retrodiscal pad.

4. MUSCLES OF MASTICATION

MASSETER MUSCLE (Figs. 11,16,17) The masseter

was a large muscle covered on its lateral surface by skin, subcutaneous fascia, fat, the buccal pouch, anteroinferiorly, and the parotid gland, posterosuperiorly. (Fig. 3) The ramus was on the medial side of the muscle.

The masseter muscle could be divided into a superficial and a deep head. Between the two heads was a layer of connective tissue and fat. The superficial plate of muscle originated from the inferior border of the zygomatic arch, posteriorly, and from the inferior and medial surface anteriorly. Anteriorly, some fibers arose from the medial and inferior aspect of the zygomatic process of the maxilla. Posteriorly, the fibers terminated about one centimeter anterior to the temporomandibular joint. The fibers ran inferiorly, in an oblique anterior posterior direction. They inserted on the angle of the mandible, from the region of the second permanent molar to a point half way up the ramus.

A tendinous plate covered the muscle superficially. It was thickest at the anterior superior corner of the muscle and fanned out inferiorly and posteriorly diminishing in thickness until it disappeared.

The deep head of the masseter originated from the medial and inferior aspect of the zygomatic arch. Anteriorly, the fibers arose from the medial surface of the arch. The extreme anterior fibers fused with the superficial tendon of the

temporal muscle. Posteriorly, the deep head arose from the inferior and medial portion of the zygomatic arch and from the temporomandibular ligament. The anterior fibers were the longest; they progressively became shorter going posteriorly and were vertically orientated.

The deep plate inserted into an ovoid fossa on the ramus, below the sigmoid notch. Anteriorly, the fibers inserted at the level of the occlusal surface of the mandibular second molar and diminished in length posteriorly, inserting at the level of the mandibular neck just anterior to the condyloid process.

The masseter muscle was a strong elevator of the mandible. The deep head could exert a retracting component of force when the jaw was protruded since its fibers became obliquely orientated upon protrusion. The superficial head had no ability to influence retrusive movements.

TEMPORAL MUSCLE (Figs. 16,18,19,20) The temporal muscle was covered superiorly by skin and fascia and inferiorly by the masseter muscle and zygomatic arch. It could be divided, somewhat incompletely, into two parts, a superficial and a deep head.

The superficial head arose from an area encompassed by a bony ridge, the temporal line, which extended from the posterior aspect of the zygomatic process of the frontal

bone posteroinferiorly to the occipital bone where it turned anteriorly and became confluent with the occipital ridge. This area of origin included the posterior medial aspect of the zygomatic bone, the lateroposterior one-half of the frontal bone and the temporal portion of the parietal bone. The anterior muscle fibers were vertical; the posterior ones horizontal in direction. They all converged and passed through the zygomatic arch to insert on the coronoid process, and the lateral and anterior surfaces of the ramus, terminating in a tendinous insertion on the external oblique ridge of the mandible.

The deep head originated from the squamous of the temporal bone, the temporal aspect of the parietal bone, the temporal surface of the frontal bone and the infratemporal surface of the greater wing of the sphenoid bone. The fiber direction was the same as that of the superficial head. The deep head inserted on the coronoid process, the entire sigmoid notch, and on the anterior medial aspect of the ramus. Some fibers continued downward and attached to the internal oblique ridge.

The temporalis was an elevator of the mandible. Unlike the masseter, a power muscle, it was primarily a mover. The posterior horizontal fibers could exert a retrusive force on the mandible.

MEDIAL PTERYGOID MUSCLE (Figs. 21,22,29) The

medial pterygoid was a quadrilateral muscle, having one head, on the medial surface of the ramus. It originated from the pterygoid fossa, between the large lateral pterygoid plate and small medial pterygoid plate. Some of the fibers also arose from the inferior edges of the above mentioned two plates and anteriorly from the inferior surface of the pyramidal process of the palatine bone.

The fibers proceeded laterally and posteriorly, inserting on the mandibular angle. The angle curved medially at its inferior border. The anterior border of the insertion was adjacent to the third molar and continued back to a level just inferior to the mandibular foramen.

The medial pterygoid was a powerful elevator of the mandible. It was thicker in cross section than the masseter and exerted an action synergistic with it.

The origin of the pterygoid was medial to its insertion. This anatomical position caused the muscle to exert not only an elevating, but also a medial component of force on the angles of the mandible. The influence of this medial component was evident by the inward curling of the thin gonial angle.

LATERAL PTERYGOID MUSCLE (Figs. 20, 23, 24) The lateral pterygoid extended from the base of the cranium, medially, to the mandible laterally. The muscle consisted of two

heads; a small superior and a large inferior one. The superior head took its origin from the infratemporal surface of the greater wing of the sphenoid bone and from the infratemporal surface of the temporal bone. The inferior head arose from the lateral surface of the lateral pterygoid plate. Fibers of the superior head united with those of the inferior head and inserted into the capsule, on the anterior portion of the mandibular neck, and on the anterior edge of the condyle.

The lateral pterygoid was a protractor of the mandible. Upon contraction, it moved the condyle forward and downward along the posterior slope of the articular eminence.

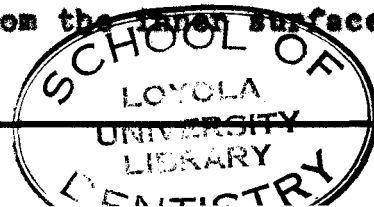
DIGASTRIC MUSCLE (Figs. 15,16,25,26,28) The digastric muscle of *Macaca mulatta* consisted of one anterior and two posterior heads. The anterior head was a thick plate of muscle inferior to the mylohyoid, extending from one premaseteric notch to the other - the digastric sling. (Schwartz & Heulke 1963) The fibers of the anterior head arose from the convex surface of the intermediate tendinous loop which was just anterior to the hyoid bone. The fibers of the anterior head inserted on the medio inferior border of the mandible, below the mylohyoid line. The intermediate tendinous loop was attached by a thin layer of fascia to the hyoid bone. The anterior head was thin at its insertion and thickest at its origin from the intermediate tendon.

The two bilateral posterior heads originated from a smooth surface on the occipital bone, inferior and posterior to the external auditory meatus. They became continuous with the intermediate tendon, anteriorly. There was no groove or tubercle to mark the origin of the posterior belly.

The posterior belly was ovoid in cross section and had its greatest width in its posterior one half. The digastric depressed the mandible downward and backward upon contraction. It could reverse its action and elevate the hyoid bone when the mandible remained stationary.

GENIOHYOID MUSCLE (Figs. 26,28,29) The geniohyoid muscle was bounded, inferiorly, by the mylohyoid, and superiorly by the genioglossus. It arose from the medial surface of the symphysis and inserted on the hyoid bone. The sublingual salivary glands bordered the muscle laterally. The muscle, in contact with the one of the other side, was triangular in cross section. It progressed posteriorly and inferiorly, and thickened slightly before attaching to the anterior surface of the hyoid bone. The geniohyoid moved the hyoid bone upward and forward, or the mandible downward and backward depending on which bone served as the origin.

MYLOHYOID MUSCLE (Figs. 27,28) The mylohyoid was a thin plate of muscle located between the digastric and the geniohyoid muscles. The fibers arose from the inner surface



of the mandible and proceeded medially to unite with the fibers of the opposite side, forming the mylohyoid raphe. The muscle plate progressed from its inferior attachment at the symphysis, gradually upward, terminating adjacent to the third molars.

The anterior fibers of the mylohyoid muscle met those of the opposite side at the mylohyoid raphe. The middle one-third of the mylohyoid muscle inserted into a tendinous aponeurosis, anterior to the hyoid bone. This aponeurosis was attached posteriorly to the hyoid bone. The posterior fibers inserted directly into the hyoid bone. On coronal section the muscle formed an obtuse "V".

Contraction of the anterior fibers of the mylohyoid muscle raised the floor of the mouth while contraction of the middle and posterior one-third elevated the hyoid bone superiorly and anteriorly. Posterior fibers directly attached to the hyoid bone depressed the mandible upon contraction, when the hyoid bone remained fixed.

5. OBSERVATIONS OF LIVING ANIMALS DURING FEEDING

In biting, *Macaca mulatta* protruded the mandible causing the incisal edges of the lower teeth to oppose those of the maxillary teeth. The mandible was then elevated bringing the incisal edges of the incisors into contact and severing off a portion of food. The food particles were then transferred by the tongue to the occlusal surfaces of the posterior teeth.

The chewing movement started with a lateral shift of the mandible toward the side on which the bolus of food was situated. The mandible was then elevated, the bolus of food engaged and the mandible shunted medially resulting in a shearing force exerted on the bolus, between the lingual surfaces of the buccal cusps of the maxillary teeth and the buccal surfaces of the buccal cusps of the mandibular teeth. The prominent canines prevented extreme lateral excursions of the mandible. Intermittently, during feeding, partially masticated food was transferred by the tongue into the buccal pouch (Fig.3). The buccal pouch of *Macaca* became quite distended and contained a considerable amount of partially chewed food. After all the available food was consumed, the food from the buccal pouch was brought back into the anterior part of the oral cavity, transferred by the tongue to the occlusal surfaces of the posterior teeth, masticated completely and then swallowed.

The biting and chewing movements were quite rapid during any one feeding; one side predominated for chewing and for the storage of food in the buccal pouch.

6. TEMPOROMANDIBULAR JOINT HISTOLOGY (Figs. 33 to 42)

TEMPORAL ARTICULAR SURFACE - Isolated areas of fibrocartilage were found at the summit of the posterior articular process. Dense connective tissue fibers of the temporomandibular ligament attached to the processes' posterior, in-

ferior, and anterior surfaces. Fibrocartilage covered the glenoid fossa and the anterior articular eminence. In the anterior one-half of the glenoid fossa, the fibrocartilage increased in thickness, continued anteriorly and was thickest at the summit of the anterior articular eminence. This fibrocartilagenous layer terminated anterior to the articular eminence. Bone resorption was observed in the lower one-third of the posterior articular process.

DISC (Figs. 33,34) The intra-articular disc was attached posteriorly by vascular loose connective tissue (retro-discal pad) to the temporomandibular capsule. The fibers in the posterior and anterior one-third of the disc were arranged longitudinally and vertically. Fibrocytes were numerous and of a stellate configuration. In the middle one-third, the thinnest part of the disc, the fibers were arranged longitudinally and the fibrocytes elongated. Anteriorly, the disc was attached directly to the temporomandibular capsule. Fibers from the disc inserted directly into the medial and lateral poles of the condyle. The disc was not attached to the capsule medially or laterally.

SYNOVIAL MEMBRANE (Fig. 36) A synovial membrane consisting of polyhedral cells and many infoldings was present in the upper and lower compartments of the joint. In the upper compartment, the membrane extended from the periphery of the

superior edge of the disc to the connective tissue layer of the temporal bone, anteriorly, posteriorly, medially and laterally. No synovial membrane was present in the center of the glenoid fossa or disc.

In the lower compartment of the joint the synovial membrane extended from the inferior edge of the disc downward along the capsule and then was reflected superiorly and became continuous with the connective tissue covering of the condyle.

TEMPOROMANDIBULAR CAPSULE AND LIGAMENT (Figs. 33, 34, 42) The capsule surrounded the joint on its medial, anterior, lateral and posterior surfaces, and consisted of dense connective tissue fibers which were more numerous posteriorly and laterally. Laterally, the fibers were thick and formed the temporomandibular ligament. Striated muscle fibers of the masseter were found dispersed among the connective tissue fibers of the temporomandibular ligament. Medioanteriorly, fibers of the lateral pterygoid were attached to the capsule.

CONDYLE (Figs. 33, 34, 35, 37) The condyle consisted of bony trabeculae between which were marrow spaces. The articulating surface of the condyle was covered by a layer of dense connective tissue. Beneath the connective tissue was a layer of hyaline cartilage which was thickest, posterosuperiorly. This cartilage layer represented the endochondral growth center of

the condyle. It can be surmised that the mandible grows downward and forward since the greatest center of endochondral activity was at the postero-superior surface of the condyle.

Resorption of bone by osteoclastic action was observed on the medial and lateral surfaces of the mandibular neck (Fig. 35). This was normal remodeling of bone. The resorption occurred along two concave lines, one extending from the medial and the other from the lateral pole of the condyle, downward to the mandibular neck. This resorption continued until the condyle stopped growing.

The hyaline cartilage "cap" was divided into three zones according to Sarnat and Engel.

1. Chondrogenic zone - This was a cell rich layer, immediately below the dense connective tissue, consisting of many chondrocytes and little intercellular substance. The cells were elongated parallel to the surface of the condyle and stained basophilic.
2. Cartilagenous zone - In this zone the cells are large and spherical and there was much more intercellular substance. In the lower layers of this zone the chondrocytes enlarged and then degenerated.
3. Osseous - This zone consisted of thin, immature, bony trabeculae. Many degenerated chondrocytes were seen in this area. They stained a light purple.

CHAPTER V

DISCUSSION

The normal anatomy of the masticatory apparatus of three animals, twelve, fifteen and seventy-two months old respectively, has been examined. Age did not basically effect the muscle anatomy, although it did exert an effect on the dentition and on the temporomandibular joint histology. Although some aberrant anatomical findings may be found in some specimens in this area, the data presented can be considered to represent the normal anatomy of the masticatory apparatus of the *Macaca mulatta* monkey.

Although the head and neck anatomy of this primate is, in general, similar to that of man, it is not identical and these differences between *Macaca mulatta* and *Homo sapiens* will be discussed in the hope of making the anatomy of *Macaca mulatta* more meaningful.

According to Sicher (1952) the fibers of the deep and superficial masseter heads of man cannot be separated anteriorly. In *Macaca* these two heads can be separated completely into two separate entities. The extreme posterior fibers of the deep head originate directly from the temporomandibular ligament in *Macaca*, while in man the deep head's post-

erior fibers do not attach to this ligament. The insertion of the deep head of the masseter muscle constitutes another difference. In the Macaque, the deep head inserts into a shallow fossa high on the ramus of the mandible. The fibers of this head are short superoinferiorly and are vertically orientated. Upon protraction of the mandible they become obliquely orientated and then can exert a retracting force on the protruded mandible. The mandibular angle, at the insertion of the masseter, is devoid in Macaca of any osseous ridges or tubercles, which is not the case in man. The area of insertion of the medial pterygoid, the medial surface of the gonial angle, curves medially. In man the gonial angle flares laterally.

This medial curling is due to two factors:

- 1) In Macaca the medial vector of force exerted on the gonial angle by the medial pterygoid muscle is counterbalanced only by the superficial head of the masseter muscle, since the deep head inserts into a fossa high on the ramus. Thus, the medial vector of force of the large medial pterygoid is much greater on the gonial angle than the lateral vector of force exerted by the smaller superficial head of the masseter muscle.
- 2) The thinness of the bone of the posterior portion of the Macaque ramus makes it susceptible to the stronger muscular force. It was observed that gonial curling was not present in young

animals. Thus osseous remodeling according to Wolf's law, occurs in this area as the animal matures. The gonial angle of man is more massive. Also both the superficial and deep heads of the masseter insert at the mandibular angle in man. Thus, forces exerted by the medial pterygoid are counterbalanced by both heads of the masseter, resulting in an equilibrium of muscular forces on the gonial angle of man. The internal oblique ridge which serves as the insertion for the deep head of the temporalis, is much more developed in Macaca, and the superficial head of the temporalis inserts much lower on the lateral surface of the ramus than in man. The anterior head of the digastric muscle in Macaca, unlike that of man, forms a continuous muscular plate between the bodies of the mandible. The fibers in the midline are anteroposteriorly orientated and become mediolaterally orientated in the posterior portion of the anterior belly. The digastric with the mylohyoid are the prime movers of the floor of the mouth in Macaca. In man, the anterior bellies of the digastric muscles are not united and do not contribute to floor of the mouth movements. The middle fibers of the mylohyoid muscle insert into a "square" of tendinous tissue, anterior to the hyoid bone and attached to it. This tissue is not present in man. The Macaca mylohyoid is thin and not as well developed as that of man.

The permanent dentition of *Macaca mulatta* differs

from that of man. In the monkey, the posterior dental arches are parallel to each other with a slight constriction occurring in the region of the third molars. This constriction in the lower arch limits the space available for the posterior part of the tongue. There is no impingement on third molar eruption by either the ramus in the mandibular dental arch or by the pterygoid process of the sphenoid bone in the maxillary arch, as occurs in man. The anatomical crowns of the mandibular central and lateral incisors extend, labially, well beyond the inferior border of the mandible. In man the incisor crowns are in the same plane as the lower border of the mandible.

The morphology of the individual teeth differs from that of man. The monkey canines, both maxillary and mandibular, are much more massive. The monkey maxillary and mandibular molars have two buccal cusps and two lingual cusps. Each buccal cusp is connected to the lingual cusp by a ridge of enamel. There is no oblique enamel ridge in the maxillary molars, connecting the mesiolingual cusp to the distobuccal cusp as exists in man. A third distal cusp on the mandibular third molar was another difference between the two primates. The crown of the mandibular first bicuspid of the Macaque is tilted posteriorly to allow space, (primate space) for the large maxillary canine and in like manner a diastema (primate space) exists between the maxillary lateral incisor and canine to

facilitate occlusion with the mandibular canine. The monkey bicuspid's are relatively much smaller in coronal diameter than those of man. Since the lower border of the nasal orifice is in close proximity to the alveolar process the roots of Macaca's central incisors diverge laterally.

The temporomandibular joint histology and mandibular movements are the same as those of man.

The cranial skeletal differences between Macaca mulatta and Homo sapiens are many. The anteroposterior length of the maxilla of Macaca is much longer, giving a rectangular appearance to the dental arch. The zygomatic process of the maxilla originates, laterally in the region of the second maxillary molar while in man it begins in the area of the first maxillary molar. The incisive foramen in the monkey is large and divided in half by a thin bony ridge; in man no such bony ridge is present. There are several infraorbital foramina in the monkey which are more lateral than the usual single infraorbital foramen of humans. The frontal processes of each maxilla come in contact with each other superior to Macaca's nasal bones at the maxillary frontal suture. In man, the frontal processes are adjacent to the nasal bones but never unite superiorly. The pyriform aperture's shape is inverted to that of man's, narrow inferiorly and wide superiorly. The inferior orbital fissure does not extend to the zygomatic bone laterally,

but is limited to the posterior one-third of the monkey's orbital floor. The pterygopalatine fossa is constricted and does not extend very far inferiorly. This is due to the much larger pyramidal process of the palatine bone having a greater area of contact with the pterygoid process, than in man. The larger lateral pterygoid plate affords a greater area for the origin of the lateral pterygoid muscle than exists in man.

Since the *Macaca* cranium is relatively long anteroposteriorly the zygomatic arches are longer anteroposteriorly and flare out more laterally. The foramen magnum of the monkey faces posteroinferiorly since it is situated more superiorly on the occipital bone than the human foramen magnum, which faces directly inferiorly.

The bodies of the Macaque mandible are fused at the symphysis and are parallel to each other. *Macaca mulatta*, like other lower primates has a "Simian shelf" not present in man. This shelf is a result of the anterior teeth being labial to the inferior border of the mandible. The mental foramen is situated very close to the lower border of the mandibular body. The internal oblique ridge is more pronounced and extends farther lingually than in man. The mandibular neck is much shorter and the Sigmoid notch shallower in *Macaca*. The articular surface of the condyle faces directly upward and not anteriorly, and the condylar angle (angle between condyle and

inferior border of the mandible) is less, in Macaca.

The glenoid fossa of the monkey is shallow, almost being horizontal, mediolaterally, and is narrow anteroposteriorly. The posterior articular process is much larger in the monkey. The anterior articular eminence is not very prominent and is not concave mediolaterally as in man. The squamosal surface of the temporomandibular joint has a greater surface area in Macaca. Actual articulation between the condyle and temporal squama occurs along the posterior slope of the anterior articular eminence as in the human joint. This posterior slope, in Macaca, is shallow and causes little inferior displacement of the mandible when the jaw is protruded. The glenoid fossa of the Macaque does not have a medial or lateral bony lip which could limit condyler movements in these directions, as in man.

The temporomandibular discs of the two primates differ. The superior surface of the disc of man is convex mediolaterally and concave anteroposteriorly while the superior surface of the disc of Macaca is for the most part horizontal mediolaterally and slightly concave anteroposteriorly.

CHAPTER VI

SUMMARY & CONCLUSIONS

It was the purpose of this investigation to make an integrated study of the normal masticatory apparatus, namely the skeleton, teeth, muscles and temporomandibular articulation, of the *Macaca mulatta* monkey. A detailed description of the skull, permanent dentition, masticatory muscles, temporomandibular joint, including histologic sections, was presented along with observations on living animals during feeding. These findings were then compared to the normal anatomy of the masticatory apparatus of man.

There were many similarities between the masticatory apparatus of *Macaca mulatta* and that of *Homo sapiens*, due to the fact that they are both members of the primate order.

Many differences in the masticatory apparatus of the two primates were observed. These included:

MACACA MULATTA

1. Frontal processes of maxillae unite superior to the nasal bones.
2. Linear ridge of bone divides incisive foramen in half.
3. Pterygoid plates of sphenoid bone in contact with pyramidal process of palatine bone

HOMO SAPIENS

1. Frontal processes of maxillae do not unite superior to the nasal bones.
2. Linear ridge of bone does not divide incisive foramen in half.
3. Pterygoid plates of sphenoid bone in contact with tuberosity

only.

4. Narrow, short pterygo-palatine fossa.
5. No bony roof covering infraorbital groove.
6. Two to three infra-orbital foramina.
7. Lateral pterygoid plate much larger than medial pterygoid plate.
8. Lacerated foramen not present in cranial base.
9. Lower incisors anterior to the inferior border of the mandible. Simian shelf found lingual to the lower incisors.
10. Massive internal oblique ridge.
11. No mental protuberance present at symphysis.
12. Fossa present high on the lateral surface of the ramus and is the area of insertion for the fibers of the deep head of the masseter.

of maxilla laterally and with pyramidal process of palatine bone, medially.

4. Wide, long pterygo-palatine fossa.
5. Bony roof covering infraorbital groove in anterior one-third of orbit.
6. Usually one infra-orbital foramen.
7. Lateral pterygoid plate about the same size as the medial pterygoid plate.
8. Lacerated foramen present at apex of temporal pyramid in cranial base.
9. Lower incisors in the same plane as the inferior border of the mandible. Simian shelf not found.
10. Internal oblique ridge not very pronounced.
11. Mental protuberance prominent at symphysis.
12. No fossa present on the lateral surface of the ramus. Fibers of the deep head of the masseter insert at the mandibular angle.

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| 13. Gonial angle curves medially. | 13. Gonial angle does not curve medially. |
| 14. Primate spaces present between the maxillary lateral incisor and canine, and between the mandibular canine and first premolar. | 14. No primate spaces present between the maxillary lateral incisor and canine, and between the mandibular canine and first premolar. |
| 15. Maxillary first and second premolars have two buccal roots and one lingual root. Mandibular premolars have one mesial and one distal root. | 15. Maxillary first premolar has one buccal root and one lingual root. Maxillary second premolar usually has only one root. Mandibular premolars have a single ribbon shaped root. |
| 16. First maxillary or mandibular molar is the smallest in size of the three molars. | 16. First maxillary or mandibular molar usually is the largest in size of the three molars. |
| 17. Labial surface of the crown of the first premolar is inclined forty-five degrees posteriorly. | 17. Labial surface of the crown of the first premolar is vertically orientated. |
| 18. Mandibular third molar has a fifth cusp on its distal surface. | 18. Mandibular third molar does not have a fifth cusp on its distal surface. |
| 19. The long axis of the maxillary cheek teeth is inclined lingually; the long axis of the mandibular cheek teeth is inclined buccally. | 19. The long axis of the maxillary cheek teeth is inclined buccally; the long axis of the mandibular cheek teeth is inclined lingually. |
| 20. Articulating surface of the condyle faces directly upward. | 20. Articulating surface of the condyle faces upward and forward. |

30. Inferior orbital fissure does not extend to the zygomatic bone laterally.

31. Foramen magnum faces posteroinferiorly.

32. Short mandibular neck.

30. Inferior orbital fissure extends to the zygomatic bone laterally.

31. Foramen magnum faces inferiorly.

32. Long mandibular neck.

CHAPTER VII

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CHAPTER VIII

APPENDIX

Fig. 1. Anterior view of *Macaca mulatta* head.



Fig. 2. Lateral view of *Macaca mulatta* head.



Fig. 3. Lateral view of *Macaca mulatta* head dissected to show buccal pouch extending from the perioral area, posteroinferiorly. Note the parotid gland anterior to the external auditory meatus.

- A. Buccal pouch
- B. Parotid gland
- C. Masseter muscle

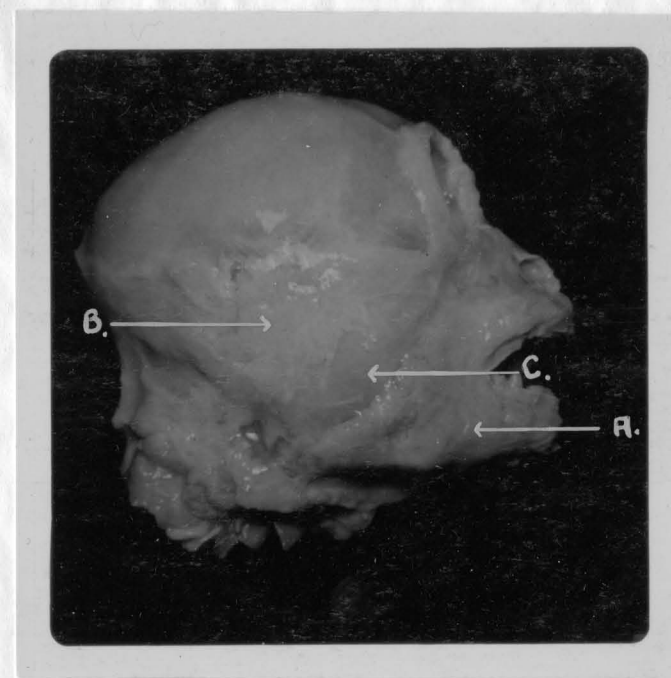


Fig. 4. Anterior view of *Macaca mulatta* skull.

- A. Maxilla
- B. Zygomatic bone
- C. Zygomatic arch
- D. Orbit
- E. Frontal bone
- F. Supraorbital ridge
- G. Vomer bone
- H. Infraorbital foramina

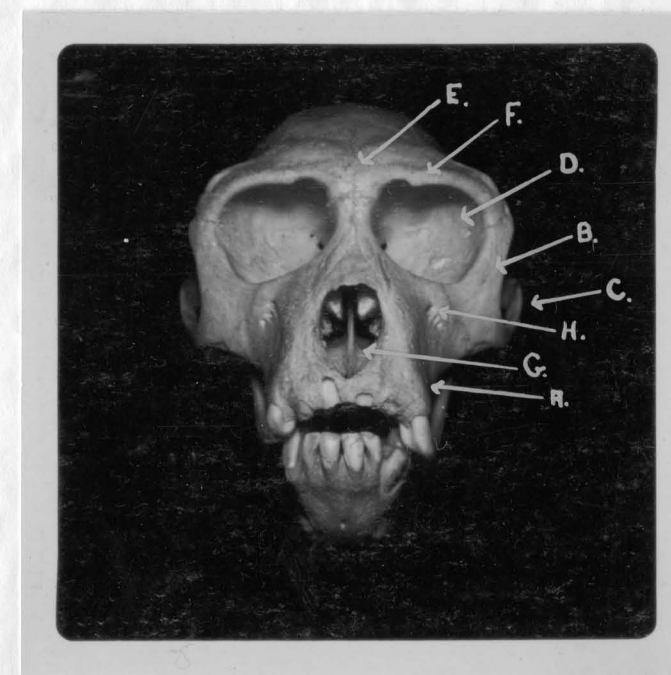


Fig. 5. Inferior view of *Macaca mulatta* cranium.

- A. Alveolar process
- B. Palatine process of maxilla
- C. Pterygoid plates
- D. Zygomatic arch
- E. Foramen magnum
- F. Nasopalatine foramen
- G. Occipital condyle
- H. Posterior articular process
- I. Occipital bone

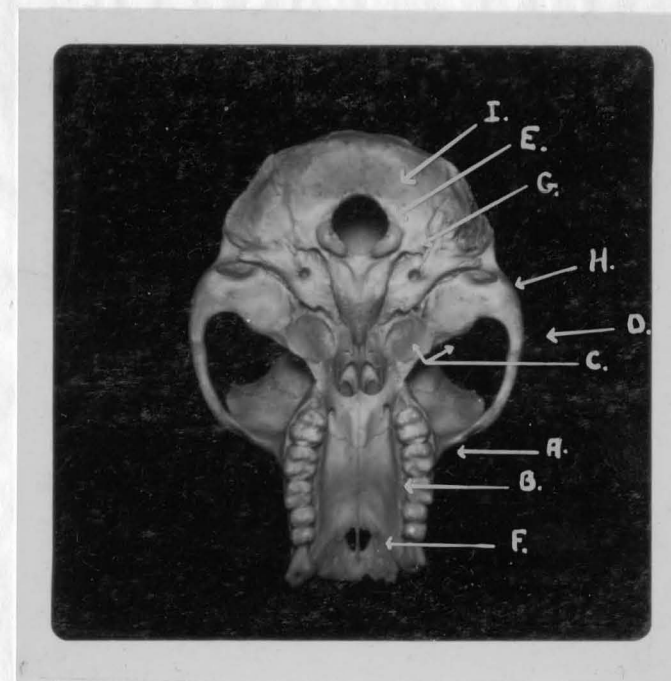


Fig. 6. Lateral view of *Macaca mulatta* skull.

- A. Maxilla
- B. Zygomatic arch
- C. Zygomatic bone
- D. Nasal bone
- E. Parietal bone
- F. Mandible
- G. Temporal bone
- H. Occipital bone
- I. Frontal bone

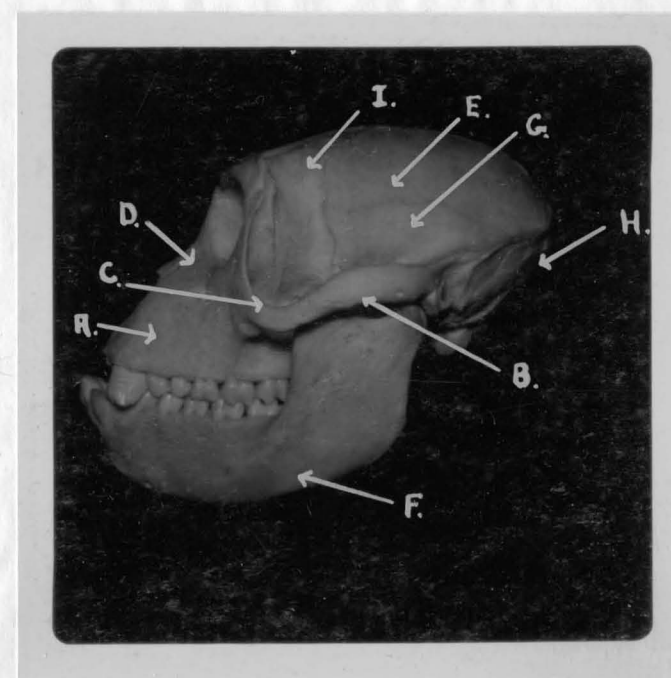


Fig. 7. Superior view of *Macaca mulatta* skull.

- A. Maxilla
- B. Zygomatic arch
- C. Frontal bone
- D. Parietal bone

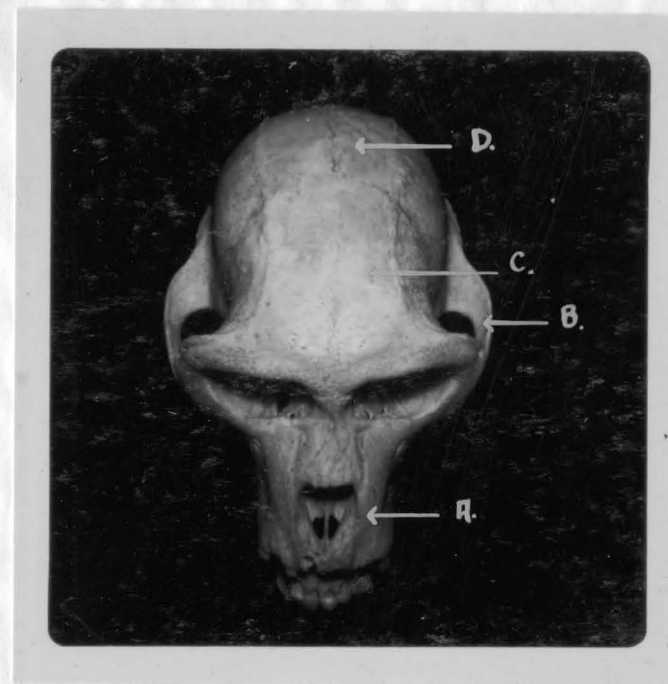


Fig. 8. Lateral view of *Macaca mulatta* mandible.

- A. Condylod process
- B. Coronoid process
- C. Ramus
- D. Body of Mandible
- E. Mental foramina
- F. Gonial angle
- G. Sigmoid notch

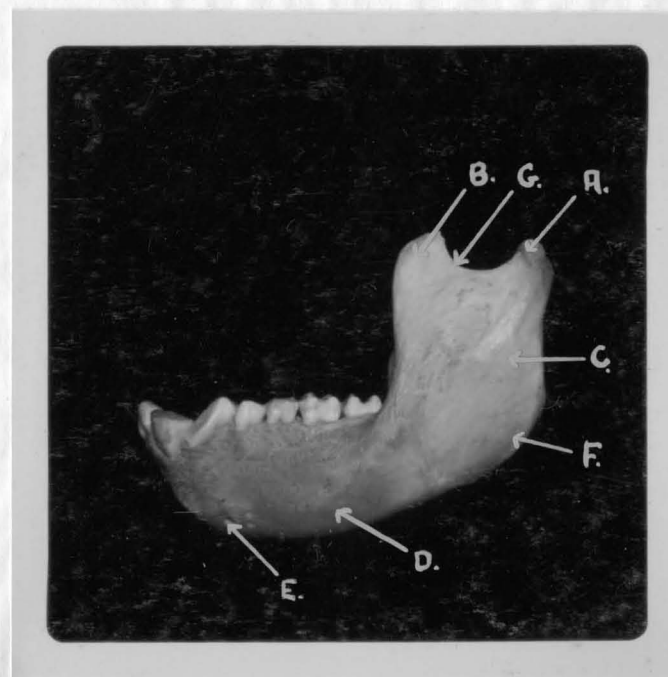


Fig. 9. Superior view of *Macaca mulatta* mandible.

- A. Condylloid process
- B. Coronoid process
- C. Gonial angle
- D. Ridge of mandibular neck
- E. Internal oblique ridge
- F. Simian shelf
- G. External oblique ridge



Fig. 10. Posterior view of *Macaca mulatta* skull.
Note medial curling of gonial angle.

- A. Pterygoid plates
- B. Zygomatic arch
- C. Occipital bone
- D. Foramen magnum
- E. Gonial angle
- F. Mandibular foramen

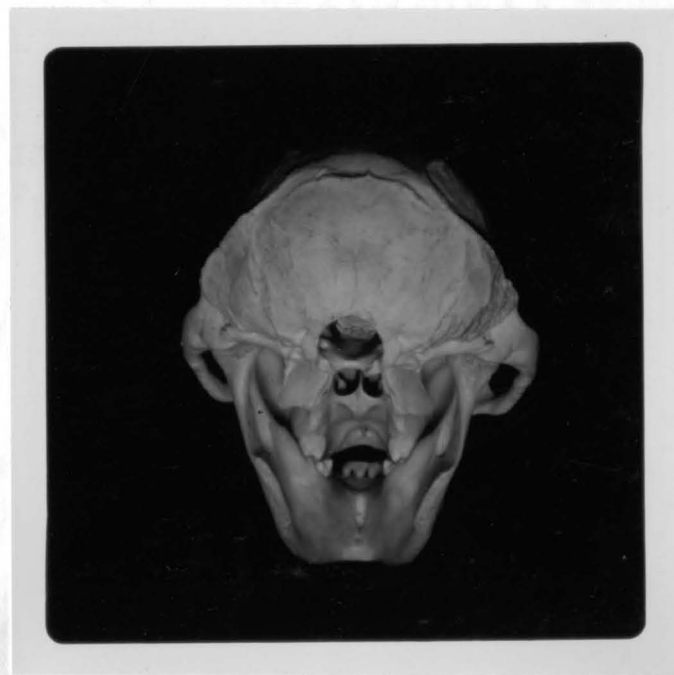


Fig. 11. Lateral view of *Macaca mulatta* dentition in centric occlusion. Note the root morphology of the individual teeth and the anterior edge of the superficial belly of the masseter muscle.

- A. Masseter muscle
- B. Zygomatic arch
- C. Zygomatic bone
- D. Nasal bone

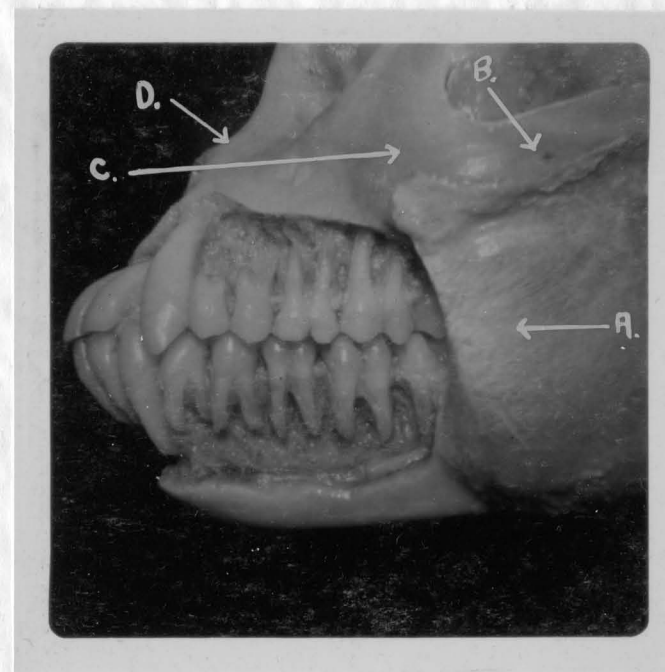


Fig. 12. Anterior view of *Macaca mulatta* dentition in centric occlusion. Note relationship of maxillary anterior teeth to mandibular anterior teeth.

- A. Orbit
- B. Masseter muscle
- C. Frontal bone
- D. Zygomatic arch

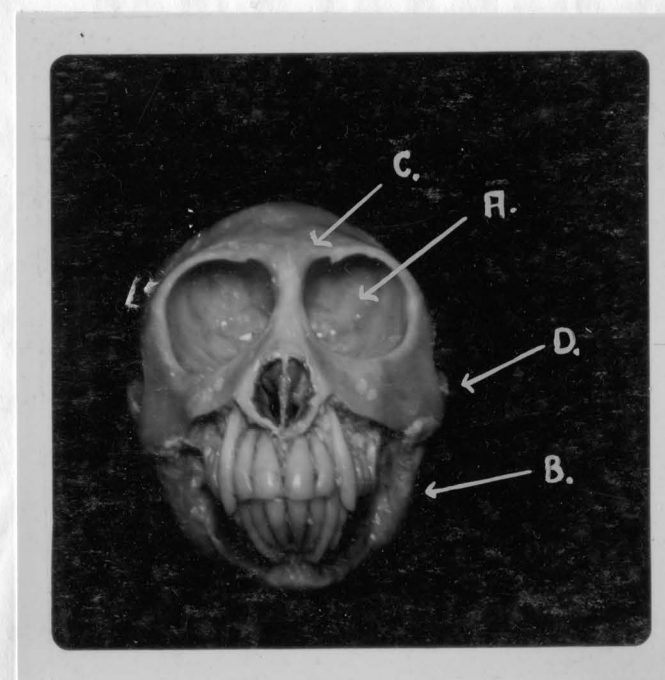


Fig. 13. Inferior view of temporal squama.

- A. Posterior articular process
- B. Squamotympanic fissure
- C. Articular fossa
- D. Lateral and medial pterygoid plates

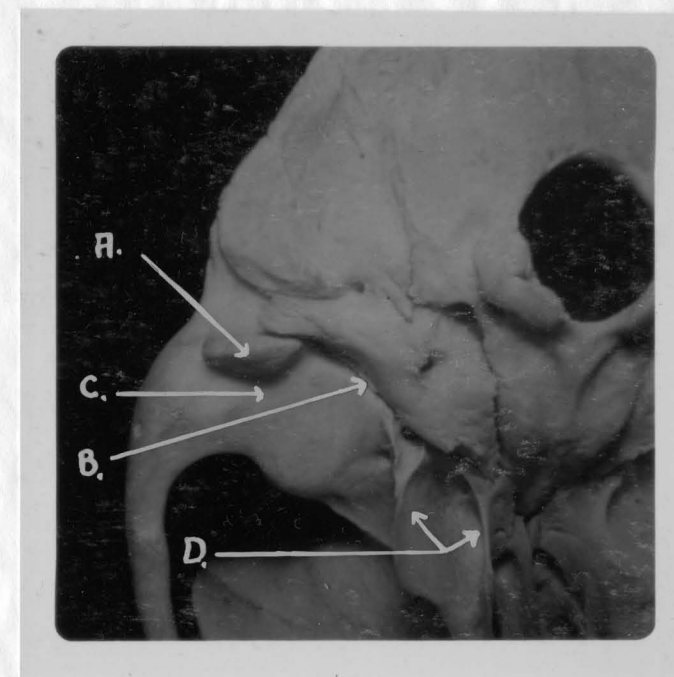


Fig. 14. Inferior view of temporomandibular articulations.

- A. Palatine process of maxilla
- B. Pterygoid plates
- C. Zygomatic arch
- D. Condyle
- E. Posterior articular process
- F. Palatine bone

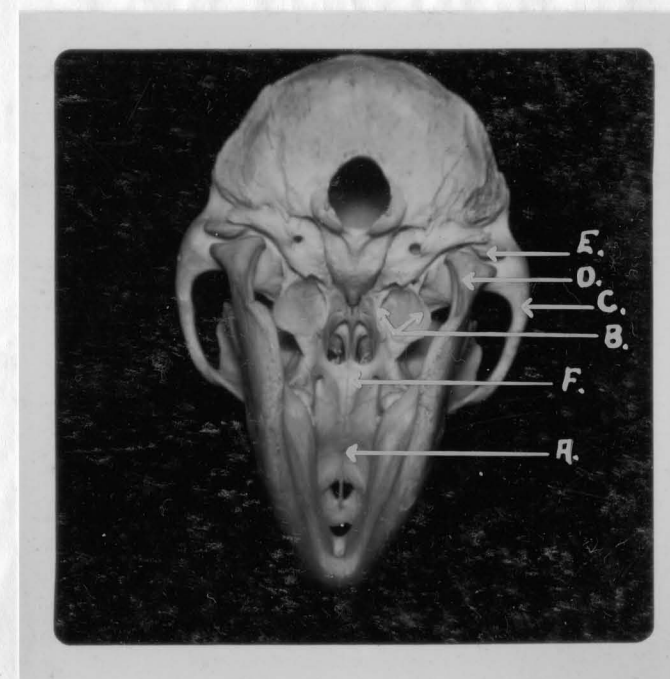


Fig. 15. Lateroinferior view of *Macaca mulatta* head dissected to show articular disc.

- A. External auditory meatus
- B. Coronally sectioned articular process and condyle
- C. Articular disc
- D. Anterior articular eminence
- E. Posterior belly of digastric muscle
- F. Masseter muscle
- G. Zygomatic arch

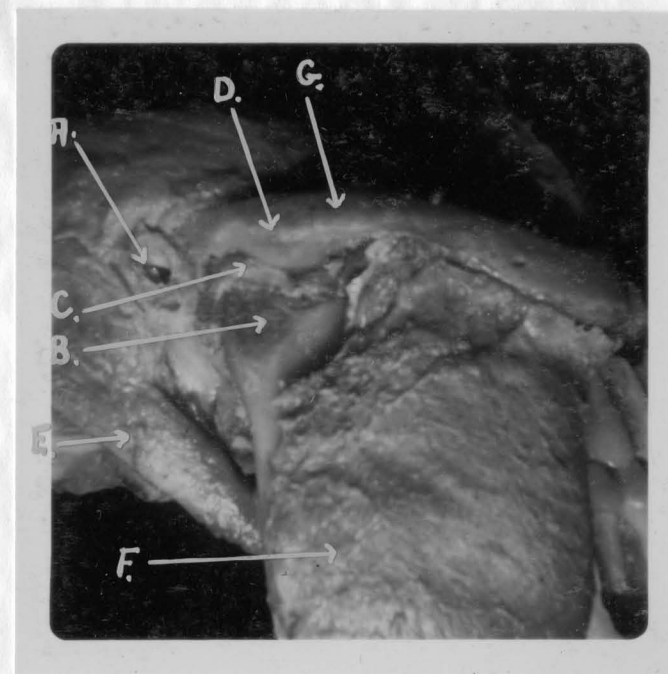


Fig. 16. Lateral view of *Macaca mulatta* head dissected to show masseter and temporal muscles.

- A. Temporal muscle
- B. Superficial head of masseter muscle
- C. Posterior belly of digastric muscle
- D. Temporomandibular capsule

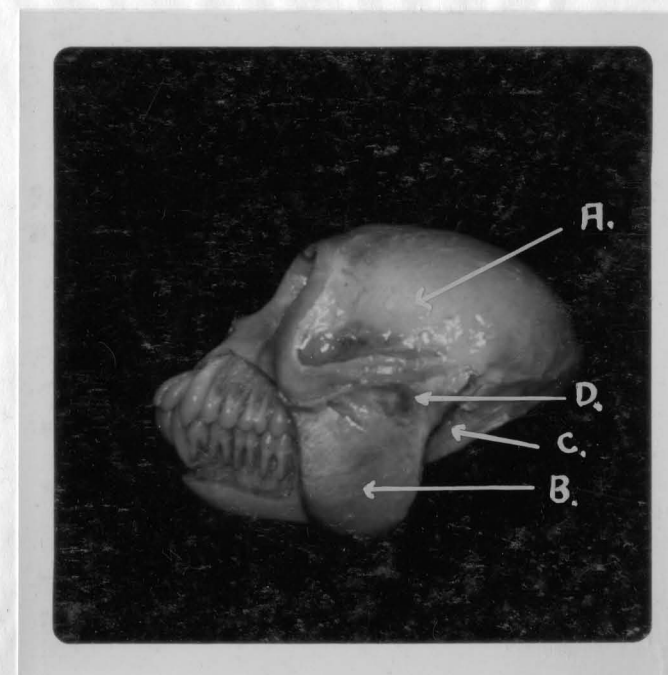


Fig. 17. Lateral view of *Macaca mulatta* head dissected to show deep head of masseter muscle.

- A. Temporal muscle
- B. Deep head of masseter muscle
- C. Superficial head of masseter muscle reflected
- D. Temporomandibular capsule
- E. Ramus
- F. Posterior belly of digastric muscle

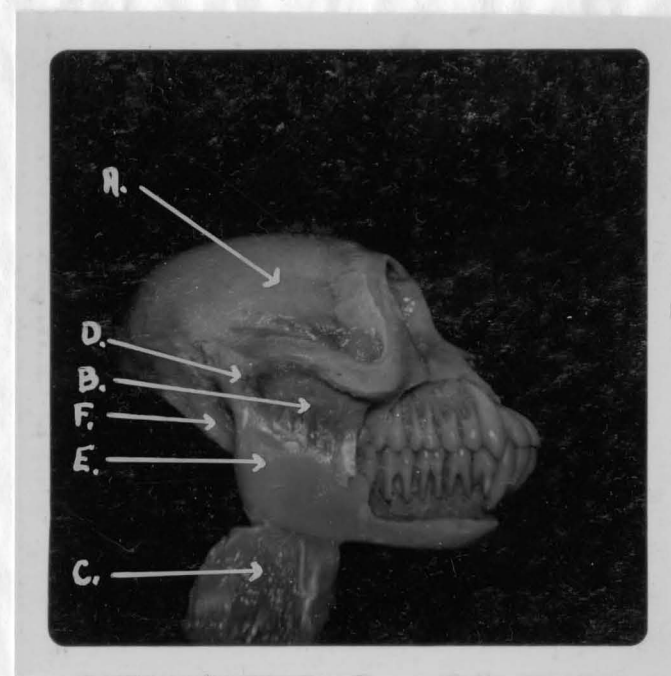


Fig. 18. Lateral view of *Macaca mulatta* head dissected to show superficial head of temporal muscle - zygomatic arch removed.

- A. Superficial head of temporal muscle
- B. Insertion of temporalis tendon low on mandibular ramus
- C. Superficial head of masseter muscle reflected
- D. Fossa of insertion of the deep head of the masseter muscle

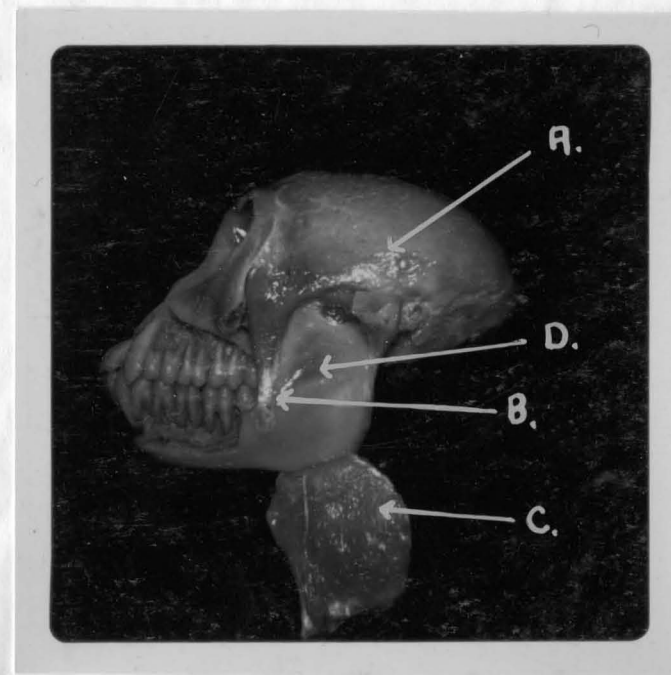


Fig. 19. Lateral view of *Macaca mulatta* head dissected to show deep head of temporal muscle. Note fossa inferior to sigmoid notch where deep head of masseter muscle inserts.

- A. Deep head of temporalis
- B. Coronoid process
- C. Masseter fossa
- D. Superficial heads of temporal and masseter muscles reflected inferiorly

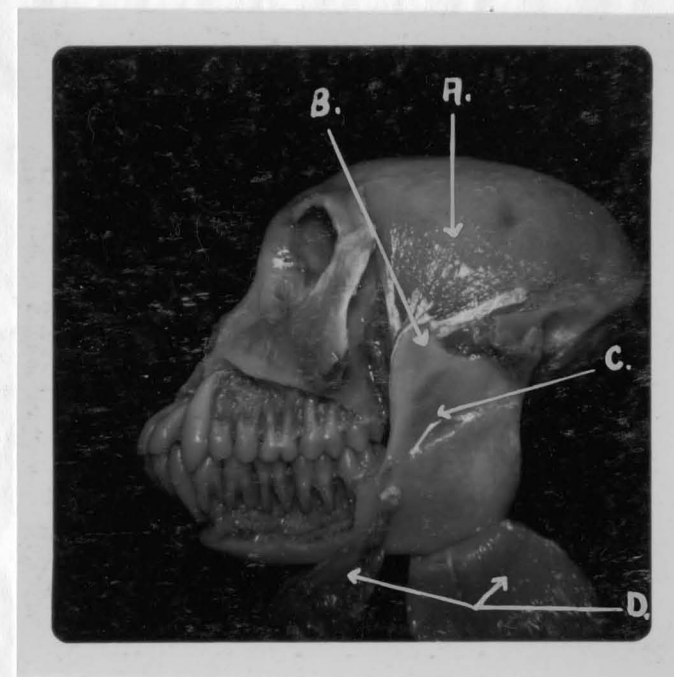


Fig. 20. Lateral view of *Macaca mulatta* head dissected to show origin of deep head of temporal muscle in region of temporal and infratemporal fossae.

- A. Deep head of temporal muscle
- B. Inferior alveolar and lingual nerves
- C. Medial pterygoid muscle
- D. Inferior head of lateral pterygoid muscle

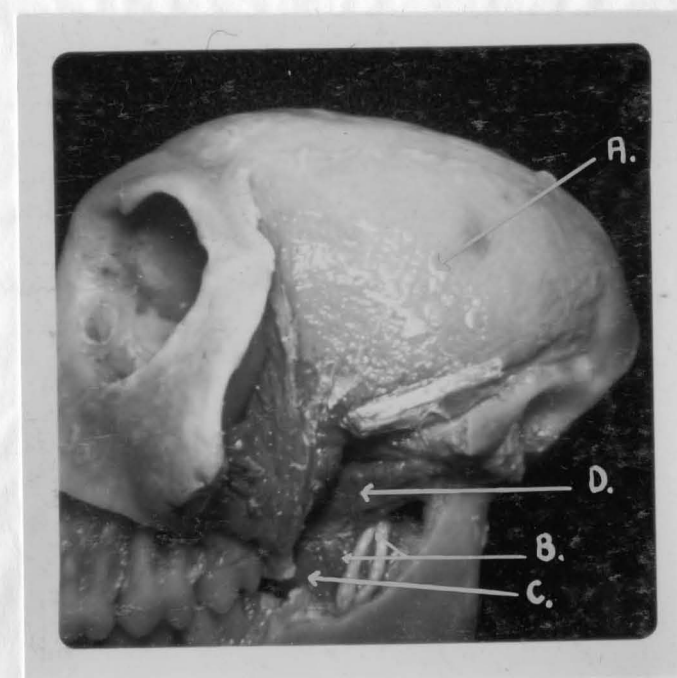


Fig. 21. Medial view of hemisected *Macaca mulatta* head dissected to show medial pterygoid muscle.

- A. Medial pterygoid muscle
- B. Medial pterygoid plate
- C. Mandible

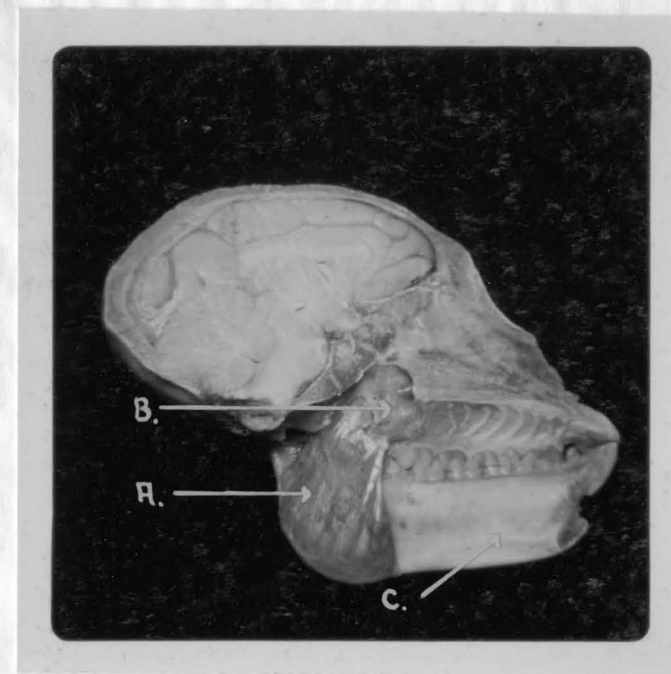


Fig. 22. Medial view of hemisected *Macaca mulatta* head dissected to show origin of medial pterygoid muscle.

- A. Medial pterygoid plate
- B. Pterygoid fossa
- C. Lateral pterygoid plate
- D. Reflected medial pterygoid muscle
- E. Inferior alveolar nerve
- F. Sectioned lingual nerve
- G. Mandible
- H. Mylohyoid nerve

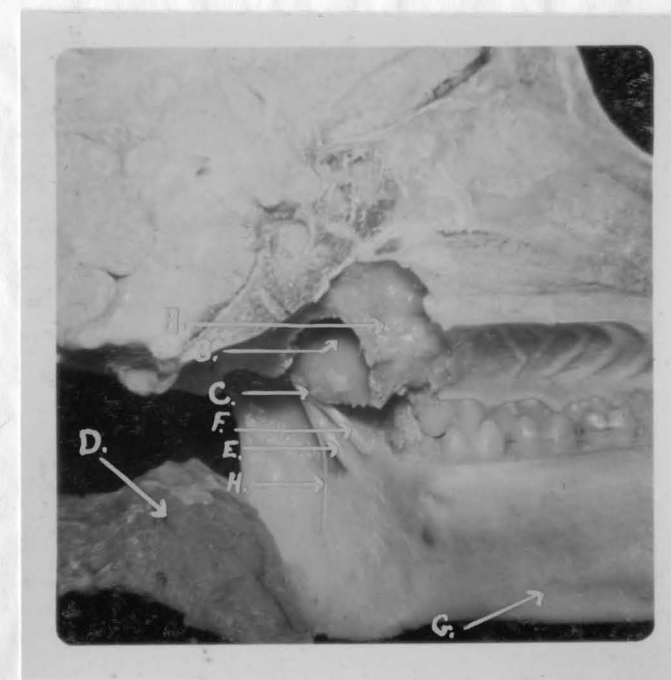


Fig. 23. Lateral view of *Macaca mulatta* head dissected to show lateral pterygoid muscle.

- A. Deep head of temporal muscle reflected superiorly
- B. Superficial head of temporal muscle reflected inferiorly
- C. Superficial head of masseter muscle reflected inferiorly
- D. Superior and inferior heads of lateral pterygoid
- E. Inferior alveolar and lingual nerves

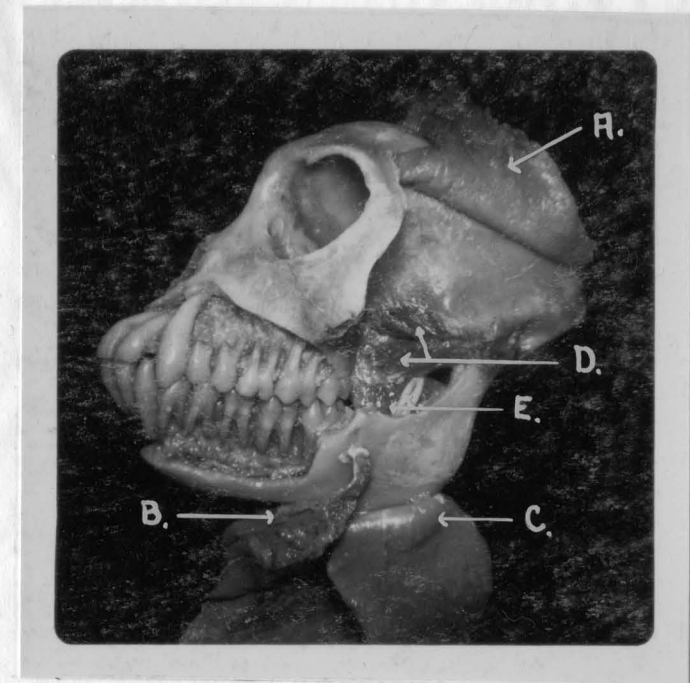


Fig. 24. Lateral view of *Macaca mulatta* head dissected to show detailed anatomy of lateral pterygoid muscle.

- A. Superior and inferior heads of lateral pterygoid muscle
- B. Medial pterygoid muscle
- C. Lateral pterygoid plate
- D. Temporal bone

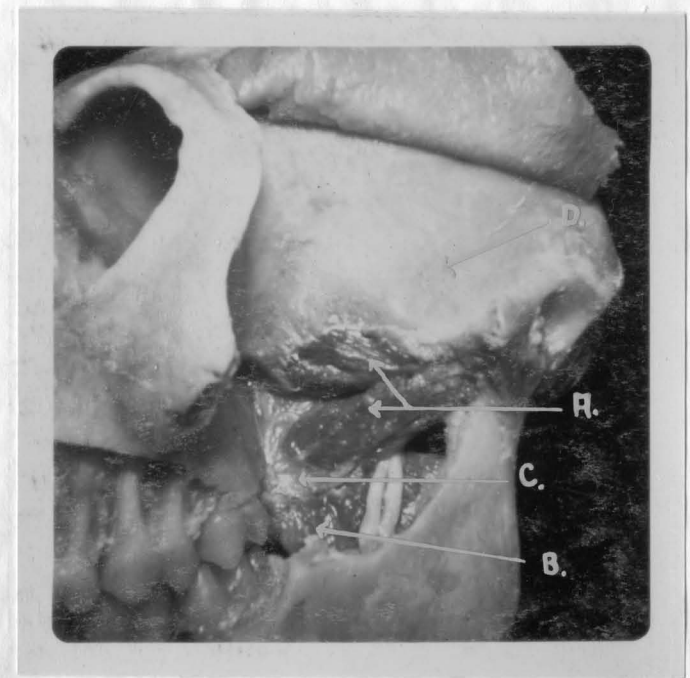


Fig. 25. Inferior view of *Macaca mulatta* head dissected to show digastric muscle.

- A. Anterior belly of digastric muscle
- B. Intermediate tendon
- C. Posterior bellies of digastric muscle
- D. Masseter muscle
- E. Occipital bone
- F. Medial pterygoid muscle

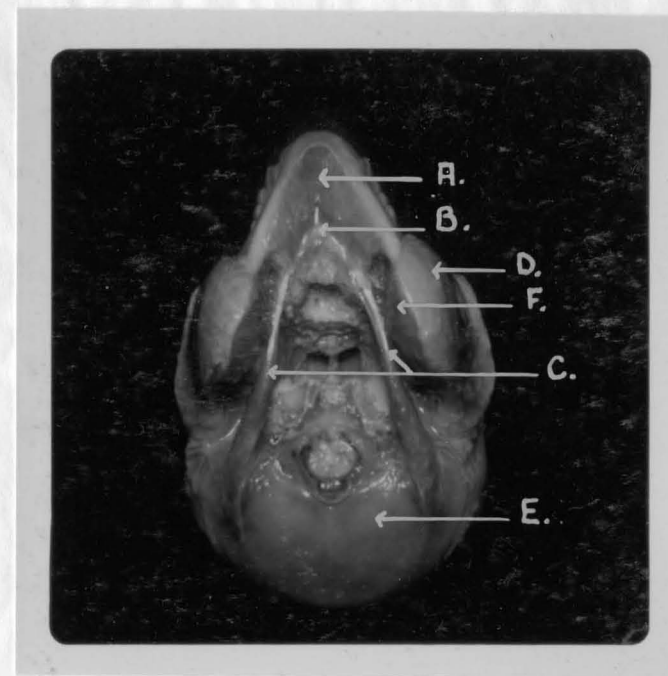


Fig. 26. Medial view of hemisected *Macaca mulatta* head dissected to show anterior and posterior heads of digastric.

- A. Anterior belly of digastric muscle
- B. Posterior belly of digastric muscle
- C. Medial pterygoid muscle
- D. Hyoid bone
- E. Mylohyoid muscle
- F. Geniohyoid muscle
- G. Genioglossus muscle

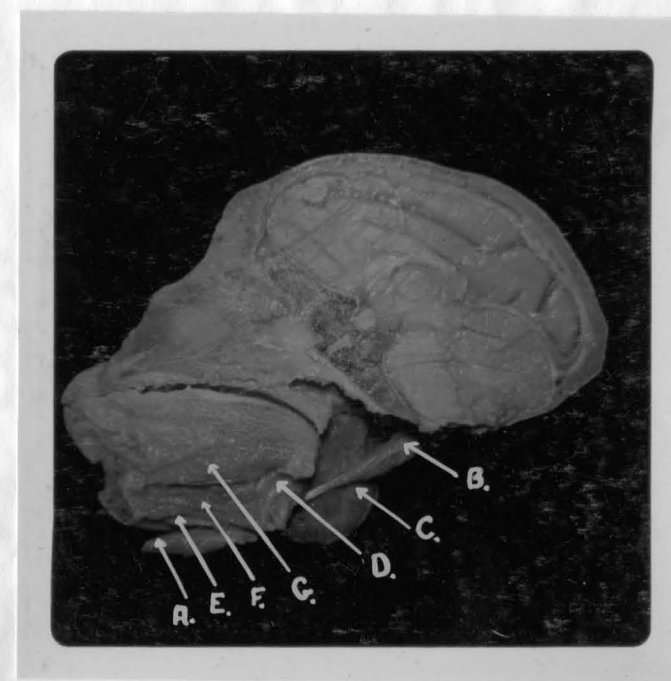


Fig. 27. Inferior view of *Macaca mulatta* mandible dissected to show mylohyoid muscle.

- A. Mylohyoid muscle
- B. Tendinous aponeurosis anterior to hyoid bone
- C. Inferior border of mandible
- D. Reflected anterior belly of digastric muscle
- E. Masseter muscle
- F. Posterior belly of digastric muscle reflected

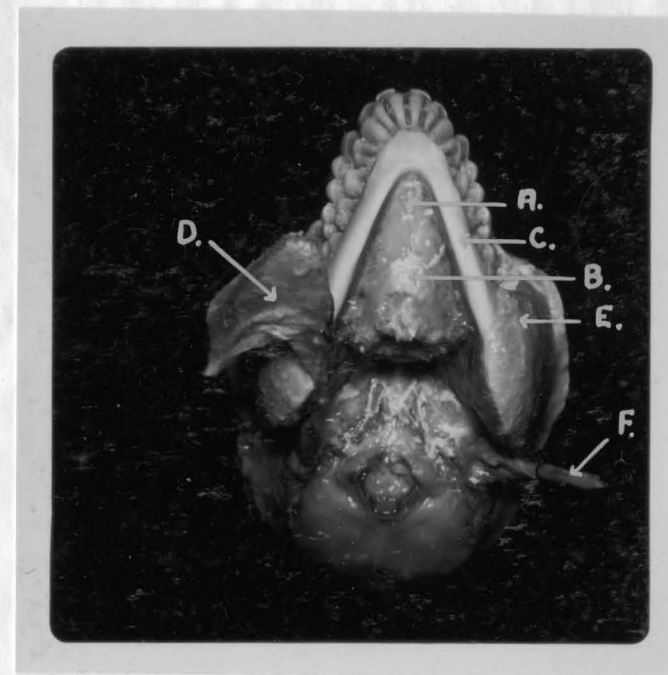


Fig. 28. Medial view of hemisected *Macaca mulatta* head dissected to show the muscles of the floor of the mouth.

- A. Genioglossus
- B. Geniohyoid
- C. Mylohyoid
- D. Anterior belly of the digastric muscle
- E. Hyoid bone
- F. Medial pterygoid
- G. "Simian" shelf

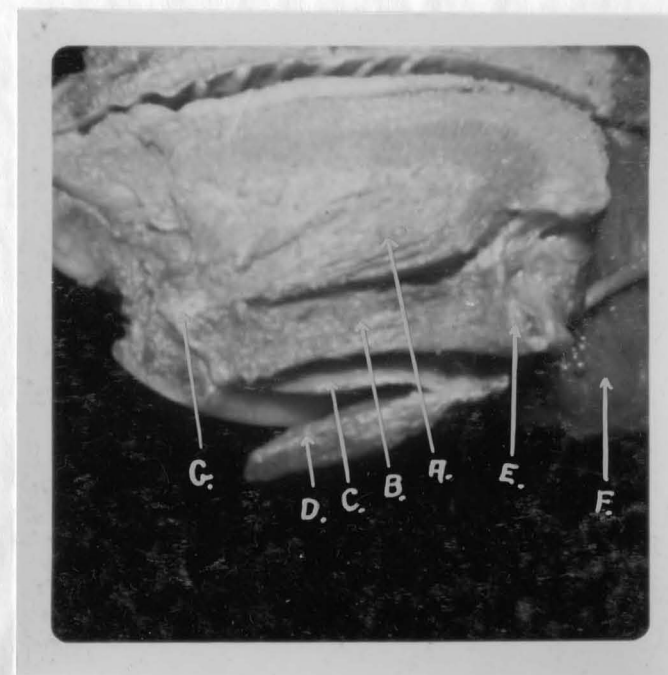


Fig. 29. ³ ~~Inferior view~~ of *Macaca mulatta* mandible dissected to show geniohyoid muscle.

- ³ A. Geniohyoid muscle
- B. Sublingual salivary glands
- C. Mylohyoid muscle incised in midline and reflected laterally
- D. Inferior border of mandible
- E. Hyoid bone

Fig. 30. Lateroinferior view of temporomandibular articulation.

- A. Zygomatic arch
- B. Anterior articular eminence
- C. Articular fossa
- D. Posterior articular process
- E. Condylod process
- F. Coronoid process
- G. External auditory meatus

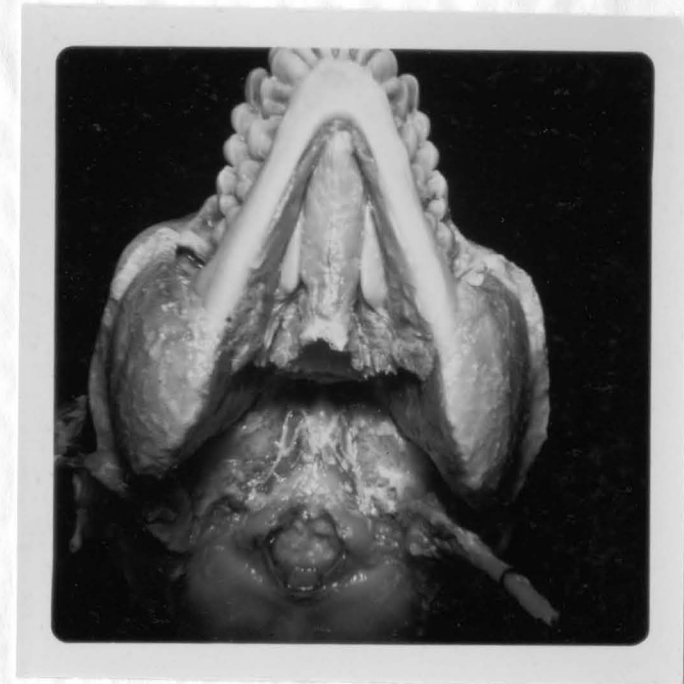


Fig. 31. Lateral cephalometric radiograph of hemisected *Macaca mulatta* head showing relationship of mandibular condyle to the articular eminence and articular fossa of temporal squama with teeth in centric occlusion.

- A. Condylloid process
- B. Posterior articular process
- C. Anterior articular eminence
- D. Glenoid fossa



Fig. 32. Posterior-anterior cephalometric radiograph of *Macaca mulatta* head showing relationship of mandibular condyle to the articular fossa of the temporal bone with teeth in centric occlusion.

A. Condylloid process

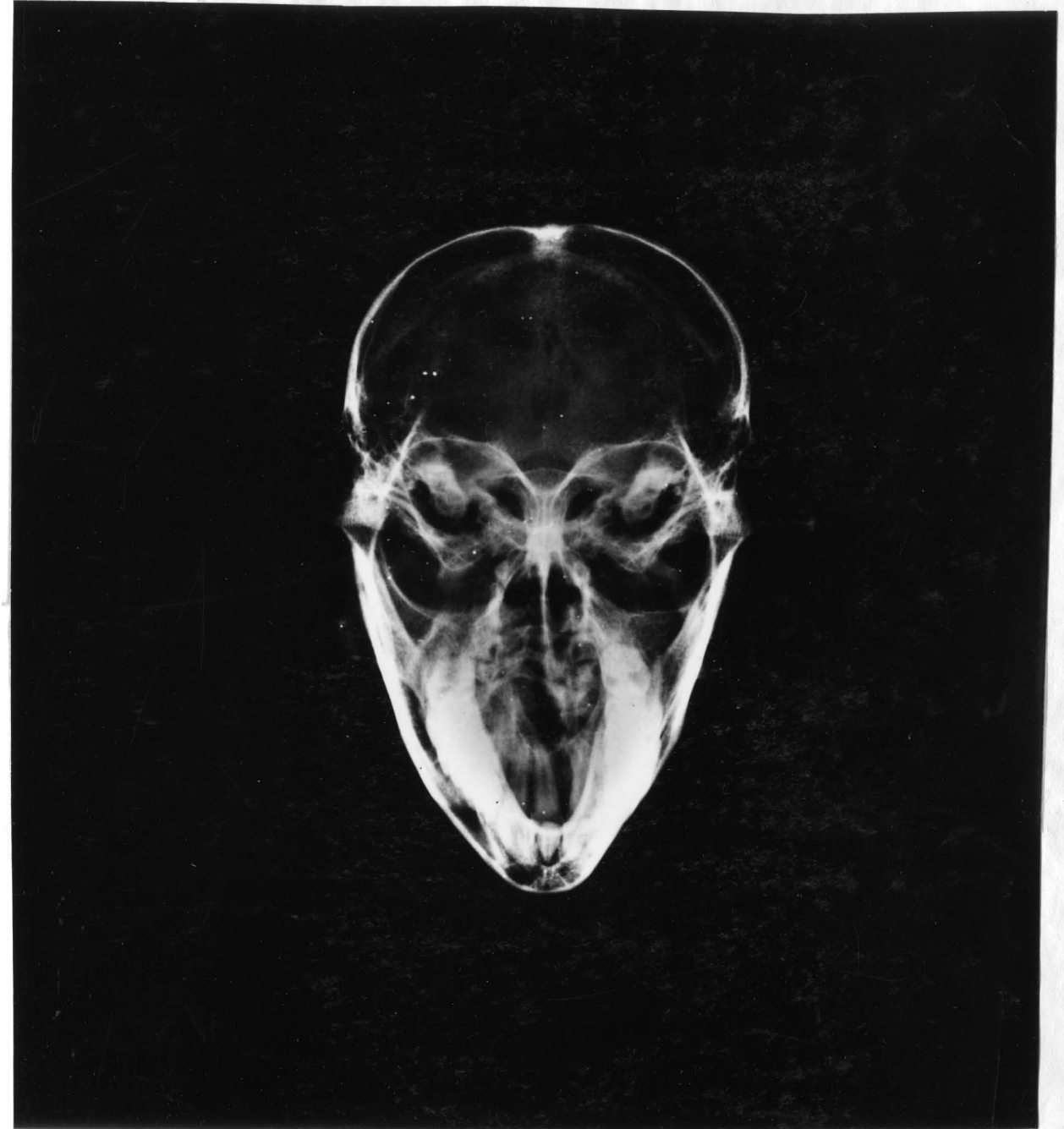


Fig. 33. Low power magnification of coronally sectioned temporomandibular joint. Hematoxylin and eosin stain.

- A. Temporal bone
- B. Dense connective tissue covering the temporal squama
- C. Upper compartment of temporomandibular joint
- D. Articular disc
- E. Lower compartment of temporomandibular joint
- F. Dense connective tissue covering the condyle
- G. Hyaline cartilage (endochondral growth center)
- H. Bony trabeculae of condyle
- I. Temporomandibular ligament
- J. Lateral pterygoid muscle

Note the independent attachment of the articular disc and the temporomandibular ligament to the condyle. There is no fusion of the disc with the ligament.

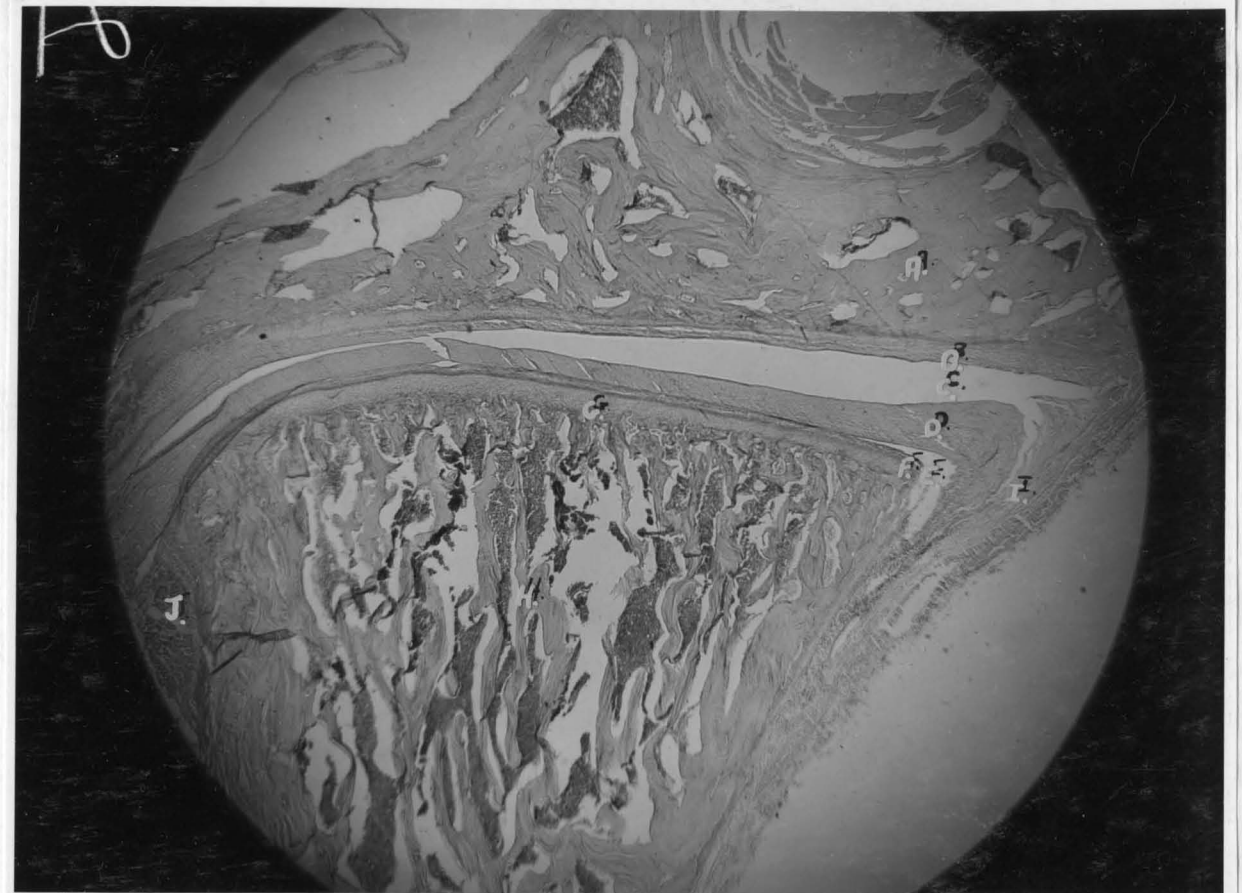


Fig. 34. Low power magnification of sagittally sectioned temporomandibular joint. Hematoxylin and eosin stain.

- A. Temporal bone
- B. Fibrocartilage covering glenoid fossa
- C. Glenoid fossa
- D. Anterior articular eminence
- E. Upper compartment of temporomandibular joint
- F. Articular disc
- G. Retrodisical tissue
- H. Lower compartment of temporomandibular joint
- I. Dense connective tissue covering condyle
- J. Hyaline cartilage (endochondral growth center)
- K. Bony trabeculae of condyle
- L. Posterior articular process
- M. Temporomandibular ligament
- N. Lateral pterygoid muscle

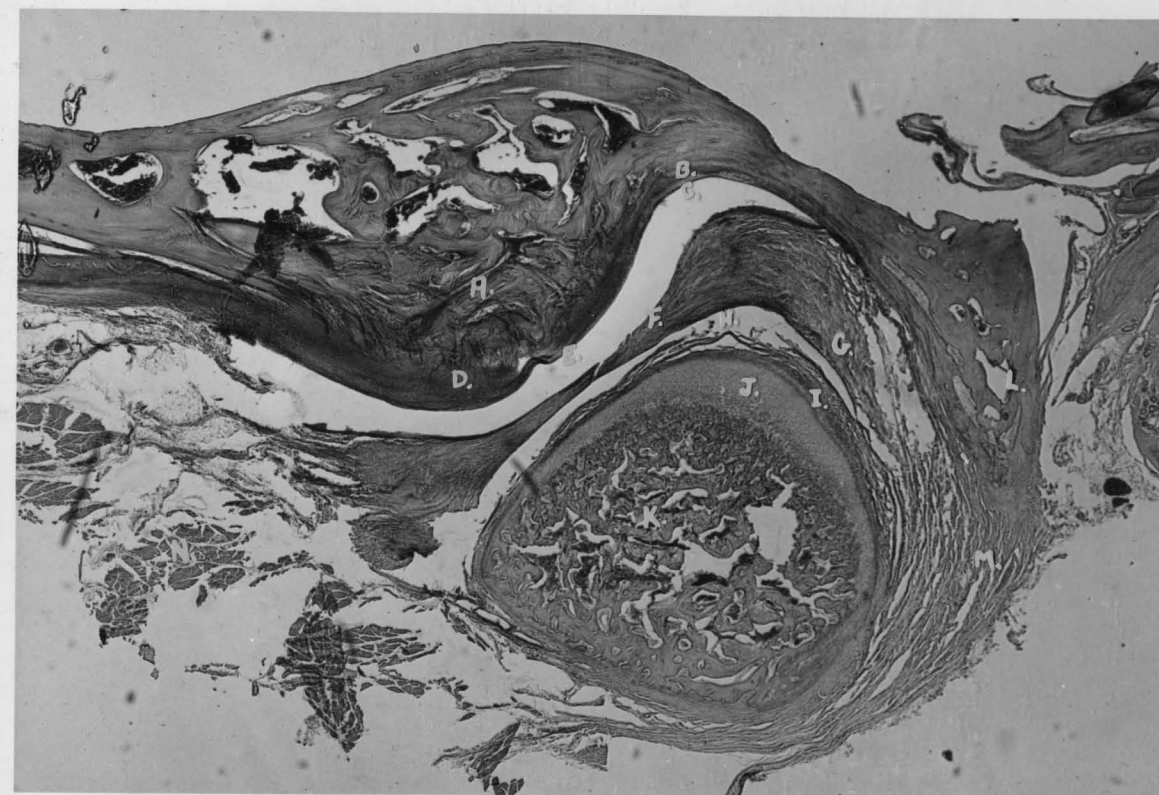


Fig. 35. Low power magnification of coronally sectioned condyle - Trichrome stain.

- A. Dense connective tissue covering the condyle
- B. Hyaline cartilage (endochondral growth center)
- C. Bony trabeculae of condyle
- D. Osteoclastic resorption of bone on medial and lateral surfaces of mandibular neck

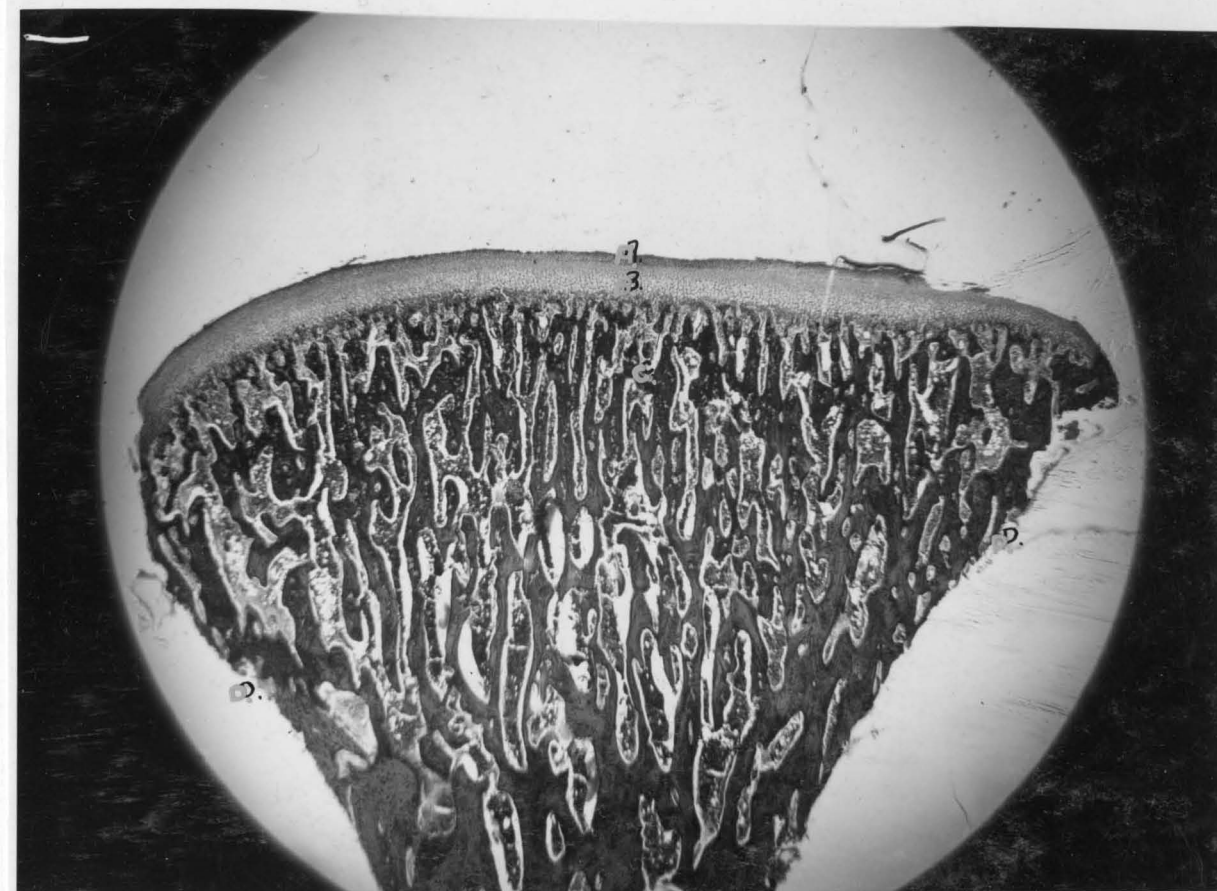


Fig. 36. High power magnification of sagittally sectioned condyle showing synovial membrane. Hematoxylin and eosin stain.

- A. Hyaline cartilage of endochondral growth center
- B. Dense connective tissue covering condyle
- C. Synovial membrane lining lower compartment of temporomandibular joint
- D. Retrodiscal connective tissue

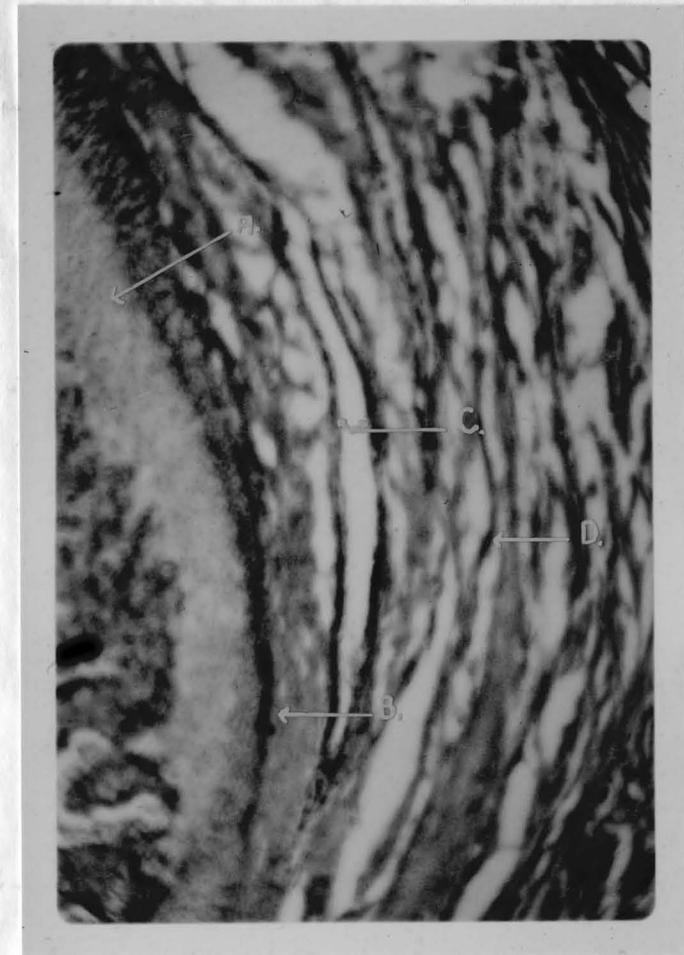


Fig. 37. High power magnification of sagittally sectioned condyle showing endochondral growth center. Trichrome stain.

- A. Hyaline cartilage
- B. New bony trabeculae
- C. Marrow spaces

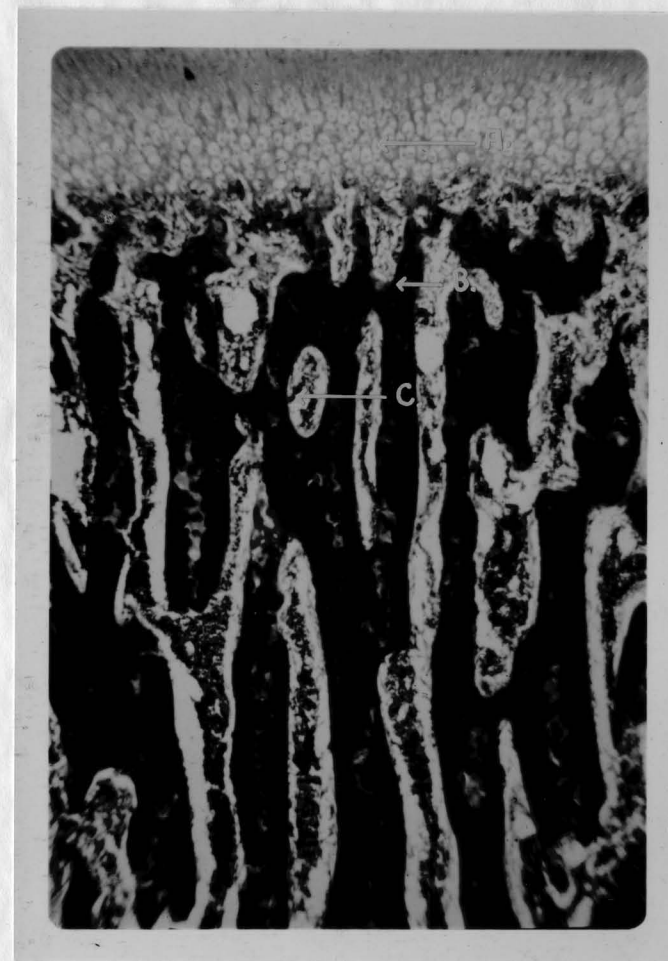


Fig. 38. High power magnification of sagittally sectioned temporal bone showing a layer of fibrocartilage covering the glenoid fossa. Hematoxylin and eosin stain.

A. Fibrocartilage

Fig. 39. High power magnification of sagittally sectioned temporal bone showing a thick layer of fibrocartilage covering the posterior slope of the anterior articular eminence. Hematoxylin and eosin stain.

A. Fibrocartilage

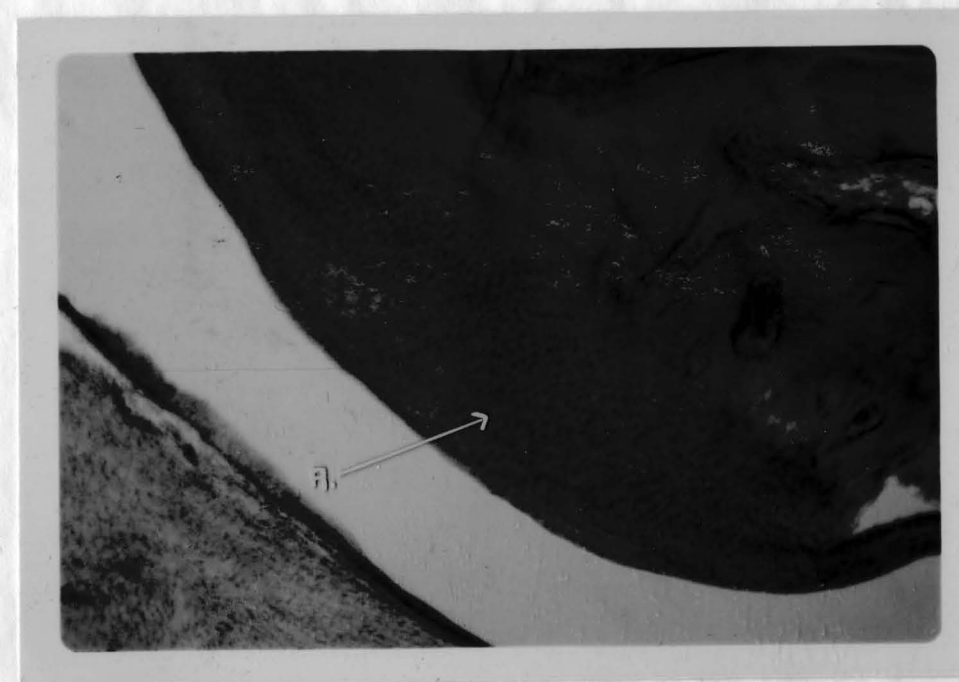


Fig. 40. High power magnification of sagittally sectioned temporal bone showing a layer of fibrocartilage covering the anterior slope of the anterior articular eminence. Hematoxylin and eosin stain.

A. Fibrocartilage

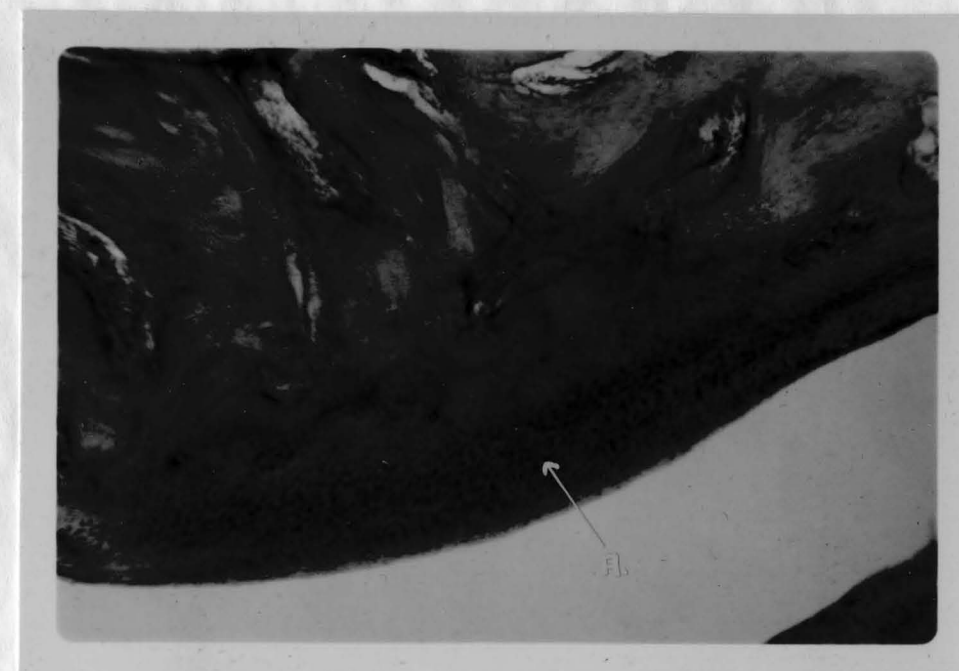


Fig. 41. High power magnification of sagittally sectioned temporomandibular joint showing fibers of the lateral pterygoid muscle attaching to the temporomandibular capsule at the anterior aspect of the disc. Hematoxylin and eosin stain.

A. Disc
B. Condyle
C. Lateral pterygoid muscle fibers
D. Temporomandibular capsule

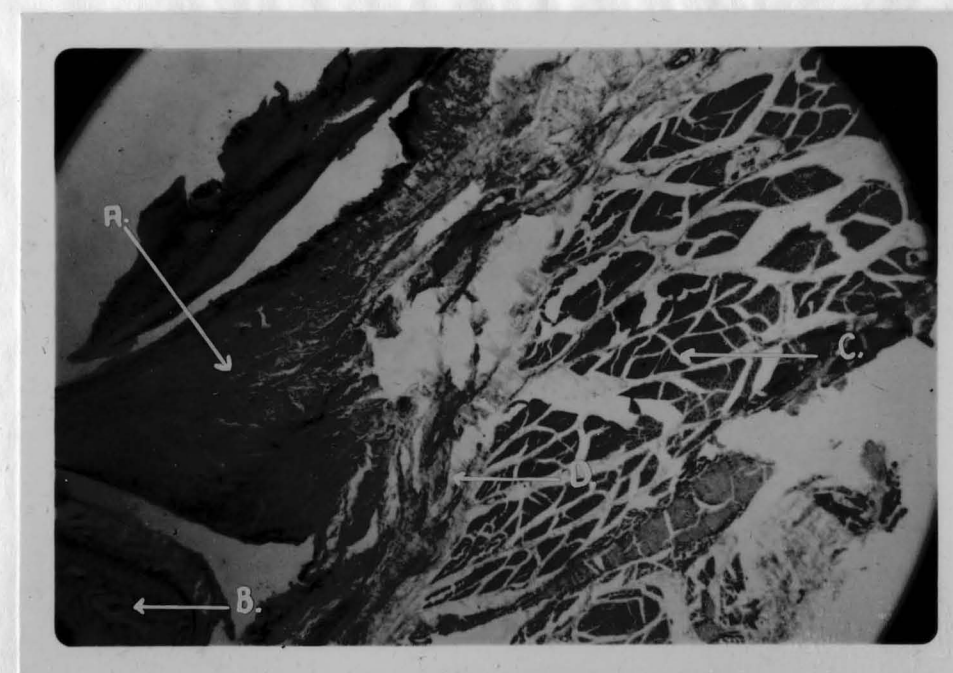
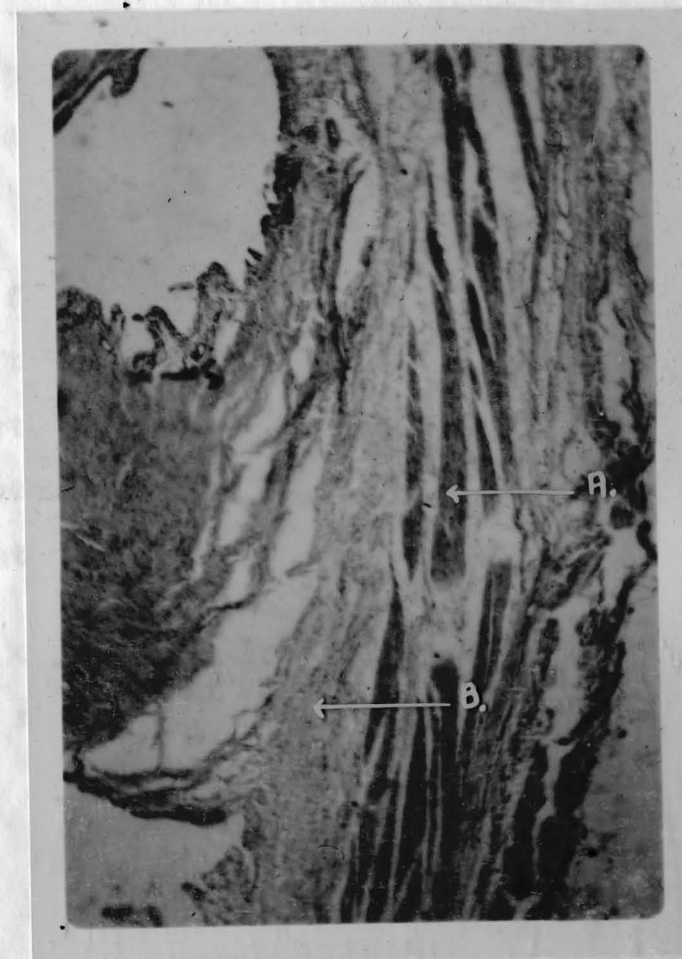


Fig. 42. High power magnification of coronally sectioned temporomandibular joint showing masseter muscle fibers interspersed among the dense connective tissue fibers of the temporomandibular ligament. Hematoxylin and eosin stain.

- A. Masseter muscle fibers
- B. Temporomandibular ligament



Date

Signature of Advisor

APPROVAL SHEET

The thesis submitted by Dr. Dennis E. Zielinski, has been read and approved by three members of the Departments of Anatomy and Oral Biology.

The final copies have been examined by the Director of the thesis and the signature which appears below verifies the fact that any necessary changes have been incorporated, and that the thesis is now given final approval with reference to content, form, and mechanical accuracy.

The thesis is therefore accepted in partial fulfillment of the requirements for the Degree of Master of Science.

5/17/65
Date

Nicholas C. Choukas
Signature of Adviser